Aerospace titanium

Through the unprecedented media coverage of the war in Iraq we are all aware of the cost to military and civilian lives if firepower is not in the right position at the critical time. Accurate and mobile ground artillery plays an important role in modern, fast-paced warfare, and a new ultra-lightweight field howitzer developed by BAE Systems RO Defence will be a huge asset to military forces when it is deployed in about a year's time.

Howitzers are self-propelled or towable cannon artillery that can fire at both high-and-low angle trajectories. The new M777 155mm lightweight howitzer will deliver a host of significant improvements compared to its predecessor the M198, which is being phased out of service.

Improved transportability – the M777 howitzer is transportable by rotor- and fixed-wing. Its compact footprint allows howitzers, prime movers and crews to be transported on a single aircraft

Improvements achieved in the M777 include a 42% reduction in basic system weight, a 25% reduction in size and retention of the 30km firing range using NATO-standard ammunition.

The M777s new capabilities and performance standards have been set by a revolutionary new design that enlists a material form unprecedented in land-based artillery – titanium Ti-6Al-4V alloy investment castings. The use of this material has enabled BAE Systems to attain the system-weight goal established by the US Department of Defense (DOD), which was seeking a new design that would contribute to its military transformation effort.

Among the many systems under evaluation, the DOD wanted a new artillery piece that could be rapidly deployed in response to threats around the globe. With a production weight of 3.7kg, the M777 fits the bill and can be transported by helicopter, transporter aircraft or ship, and towed by a 4x4 vehicle weighing 2.5 tonnes or more.

Bringing Ti-6Al-4V down to earth

Bearing in mind the system requirements, candidate materials for the howitzer's major structural components were limited. So with many objectives linked to the transportability of the new howitzer, particularly by aircraft, it is no surprise that the designers turned to Ti-6Al-4V alloy, a long-standing choice among military aircraft designers for its unbeatable combination of light weight and high strength.

Smaller than its predecessor by 25%, lighter by 42% and more nimble, the M777 can be set up in three minutes, moved out in two minutes and has improved counter-fire exchange ratios fivefold (above).

The idea of using this alloy for a howitzer's structural components was met with scepticism by some. But titanium investment castings demonstrated their ability to meet tough criteria for weight reduction and overall ruggedness during numerous tests in the developmental phase, as well as in subsequent operational assessments. In addition, the material met the durability objectives set by the joint US Army and US Marine Corps. For example, the M777 achieved considerably more than a 900 'Mean rounds between system abort' level of performance, exceeding the objective by a reassuring margin during tests. Moreover, it successfully completed a 20-year corrosion test, which called for the test gun to fire dozens of rounds after the corrosion testing had been completed.

Designing out of kilter

The M777 howitzer's designers faced a number of challenges in meeting the

shoots to earth

The US military faced a tough specification when they started development work on new lightweight howitzer ground artillery capable of rapid deployment. Frank Hoerster from BAE Systems and Jeffrey Boulet from Alcoa Howmet Castings explain how they looked to a titanium form more at home in the skies than on the ground to achieve their goals.

tough weight, transportability and on-ground mobility objectives set for the new system. The M198, itself only a few decades old, represented a major improvement over its predecessor. Making another round of order-of-magnitude improvements taxed the limits of known production technologies for land-based weapons systems.

When exploring their options for the new artillery, designers envisioned a significantly smaller system footprint, and analysis showed that the desired levels of lightness and compactness could only be achieved by design changes that incorporated new and innovative dual-function structures and pressure vessels.

The design of the new system resulted in a non-traditional artillery configuration, which placed the centre of gravity (CG) in a 'static-out-of-balance' configuration. The CG of the recoiling mass is located in front of the howitzer's trunnions when the gun is not firing, an approach that allowed engineers to design the trunnions much closer to the ground than was possible with previous generations of weapons.

Military transformations – rapid deployment means moving quickly onto and around the battlefield. The M777 howitzer can be towed on a road at 55mph and cross-country at 30mph, top. Buffer yoke – this high strength titanium casting is one of 18 structural components being supplied by Alcoa Howmet Castings to BAE Systems for the new M777 howitzer, above.

Titanium castings become design allowable

Titanium Ti-6Al-4V alloy has recently passed a major design acceptance hurdle. A military supply chain consortium made up of representatives from US government agencies, OEMs and casting suppliers, has recently published a static database for cast, hot isostatic pressed (HIP) and mill annealed Ti-6Al-4V alloy. The acceptance of this data represents a milestone in the application of investment castings for commercial and military airframes, because the data give aerospace design engineers the mechanical properties database that makes Ti-6Al-4V alloy investment castings 'design allowable'. This development removes a long-standing barrier to the conversion of fabrications to single-piece investment castings in aerospace applications. The database also documents the high degree of comparability in mechanical properties between investment-cast and wrought Ti-6Al-4V alloy components.

This new documentation provides the room temperature tensile, compression, shear and bearing information that satisfy requirements for a static database. In addition to its contribution to the static data, Alcoa Howmet Castings, a major supplier of investment castings to BAE Systems for the M777 Howitzer, has independently developed dynamic data for strain-controlled, low-cycle fatigue, fatigue crack growth and fracture toughness. The company expects this data to be included in a future edition of the Metallic Materials Properties Development and Standardisation Handbook (formerly known as the Mil-Handbook-5see 'Design-allowable castings', *Materials World*, September 2003, pp28-39).

Amphibious landing – the M777 howitzer is transportable over 83% of terrain worldwide, allowing it to reach 32% more locations than its predecessor, the heavier M198

This design strategy served to position the weapon's overall CG as low as possible. Coupled wtih a low trunnion position, this counteracts the right-hand torque generated by the weapon on firing. The recoiling mass remains within the system structure keeping the system highly stable.

Shooting through the production process

Converting fabrications to castings does more than help deliver superior performance in the field, it also gives BAE Systems superior performance in its production process. These benefits include simplifying, streamlining, standardising and containing the cost of the manufacturing process.

One significant achievement is the consolidation of 973 detailed parts into 196 single-piece castings – an 80% improvement. A part-count reduction of this magnitude helps streamline the production process by reducing or eliminating a host of manufacturing and administrative burdens that inevitably accompany alternative processes. Administrative record-keeping tasks in purchasing, supplier management, accounts payable, shipping, receiving, material handling, inventory management, inspection and more were all significantly streamlined or, in some cases, permanently eliminated as a result of part reduction.

Labour requirements were also reduced, since fabricated structural assemblies for the M777 would have required 2,458 welds, whereas the cast components need only 483 welds – another 80% improvement. Moreover, the length of the welds was cut by 77%.

Further savings accompanying conversion to the casting process include reduced raw material input requirements and much shorter manufacturing cycle times – typically 25-50% less than the cycle time for the fabrication of respective assemblies. These added savings were made possible by the tighter control of process variables that now characterises the investment casting process. Today, the parts that emerge from the process are completely interchangeable. This is a knock-on effect of continuous improvements in the precision, reliability and repeatability of the wax-injection, shell-making, vacuum-melting, casting and heat treating phases of the investment casting processes, which are all automated.

Reductions in cycle time are also achieved thanks to vertical integration within Howmet, and the expanding role the company is playing in managing finish-to-print tasks. By way of example, the majority of material and technical inputs into the casting production process were accomplished at the company's investment casting campus in Whitehall, Michigan. This single location is home to Howmet's research centre, which used SLA pattern-making in the engineering and manufacturing development stage of the project to make test articles and prototypes rapidly and relatively inexpensively.

Whitehall is also home to Howmet's titanium alloy production and speciality material production facilities. The Specialty Materials operation produces the waxes used in the pattern-making process, and is adjacent to the Ti-Alloy and Ti-Cast operations, which provide the raw material and foundry resources for the majority of the Howmet castings used in the M777 howitzer. The castings for the M777 are all hot isostatic pressed in Howmet's facility, co-located with the Ti-Cast operation.

Howmet's Tempcraft operation in Cleveland, Ohio, was called on to make the tooling for the howitzer's castings. Tempcraft also designs, builds and supplies the microprocessor-controlled wax injection equipment used to create the patterns required for the investment casting lost wax process.

Performance improvements

Performance capabilities in a range of crucial combat-support areas have also been greatly improved, such as a 25% increase in the ability to destroy enemy vehicles in close-support combat, a 70% improvement in survivability, and a 500% increase in counter-fire exchange ratios. The lightness and compactness of the new system makes it extremely nimble, and it can be set up in three minutes, move out in two minutes, and conduct firing missions from as many as four different locations within one hour.

Initial firing trials of the M777 met with success last summer and a US Army/US Marine Corp operational test and evaluation phase is scheduled for August 2004. The new lightweight howitzer looks set for its role as the US Army's new generation of medium-force weapon, with the British and Italian Armies expected to place orders soon.

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