A heat treatment process which doubles strength in aluminium die-cast

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Heat treatment has traditionally not been possible for aluminium high pressure diecastings (HPDCs) because they contain substantial amounts of entrapped gases that arise during the casting process. However, a process has recently been developed in Australia that provides the opportunity to gain large increases in mechanical properties.

High pressure diecasting is a highly efficient casting process whereby molten metal is injected at high pressure into a mould cavity. When diecastings are heated to elevated temperature for heat treatment, these gases expand causing blistering and dimensional instability. The inability to heat treat high pressure diecastings has been a limitation on their further utilisation. A process has recently been developed in Australia that overcomes these problems with the chance to obtain large increases in mechanical properties.

The patented process, developed over a five-year period from 2005 to 2010 by the Commonwealth Scientific and Industrial Research Organisation (CSIRO), overcomes these problems and provides significant improvements to tensile mechanical properties, fatigue resistance, fracture resistance and thermal heat transfer.

The process has been evaluated with a wide range of commercially produced components. All were independently assessed as having significantly increased strength and mechanical properties after treatment. The evaluations included trials on large HPDC parts (engine blocks) of up to 40kg weight. The process is particularly effective in commonly used HPDC alloys, including CA313, CA605, A380, C380, A360, A383, ADC10, ADC12, and AlSi9Cu3Fe, as well as in a number of experimental alloy compositions.

Improved mechanical properties

HPDC aluminium alloy components treated with the process typically demonstrate the following improvements in properties.

Strength and Hardness is increased significantly. The yield stress of components may be doubled for little change in tensile ductility. Increasing the hardness improves both wear resistance and machinability.

Fatigue resistance is often as high as for some wrought aluminium products. This has major implications for many components, especially those used in automotive applications, which are often fatigue limited during the design process.

Thermal conductivity is increased up to 60% above the as-cast condition, meaning that for engine or transmission applications heat can be transferred or removed more efficiently and quickly. Enhancing the thermal efficiency of the metal used in housings has special consequences for electric vehicles, where the thermal management of both the motor and inverter systems is crucial to their operation, robustness and life expectancy.

The high temperature strength and stability of the heat treated high pressure diecastings is excellent, typically showing mechanical properties similar to those at ambient temperature at temperatures up to 200°C. Extended testing at elevated temperature has also shown excellent stability of properties over long term tests at 150°C. This result has particular importance for turbocharged engine applications, where the strength at temperature needs to be higher than the levels currently achieved in HPDC engine blocks.

The procedure can be tailored to raise energy absorption during fracture. Energy absorption has been found to almost double for one common secondary alloy heat treated specifically for this purpose. This has significant implications for crash sensitive structural components made by high pressure diecasting. A range of new alloy compositions has since been developed and patented.

Heat treatment has been shown to make high pressure diecastings able to be anodised for decorative and protective (marine) finishes. This is expected to facilitate significant improvements in corrosion resistance.
How the process works
Heat treatment of aluminium involves three steps: (1) solution treatment at elevated temperature to dissolve elements into solid solution; (2), quenching to retain the elements in a supersaturated solid solution, and (3) age hardening at a lower temperature to develop mechanical properties. Conventional solution treatments for permanent mould or sand castings are for longer periods at high temperatures; for example, 6-12 hours at 540°C. In the new process, HPDC components are heated to relatively low temperatures for short periods of time for solution treatment; for example, 10-15 minutes at 430-480°C.

The time that components are held within a specified temperature range is critical since the solution treatment procedure can be entirely non-isothermal. This step is sufficient to cause at least a partial solid solution of soluble alloying elements such as Si, Cu and Mg.

Following quenching, the HPDC component is aged to a tempered condition, such as T4 (natural ageing at 22°C), T6 (artificial ageing at 150°C) or T7 (artificial over-ageing at 200°C).

Improved material properties
In common with other age-hardening processes, the new heat treatment process depends on a precipitation hardening mechanism. Production of fine nanoscale particles within the aluminium grains provides additional strength by impeding the movement of dislocations.

Similarly, the new process improves thermal conductivity through its effects on alloy micro-structure and the distribution of alloying elements. The treatment causes silicon particles to become spheroidised, and also re-distributes the copper present in the alloy as fine precipitates within the aluminium matrix, resulting in improved thermal conductivity. In heavily overaged conditions, the thermal conductivity may be increased by as much as 60% above the as-cast condition.

The process can be tailored to optimise yield strength, or to optimise fracture resistance. In general, as yield strength increases, fracture resistance goes down. T4 tempers or underaged T6 tempers produce optimum combinations of tensile properties and fracture resistance. T4 tempers for common A360 or A380 alloys (Australian designations 605 and CA313 respectively) exhibit energy absorption during crack propagation (unit propagation energy) that is approximately doubled compared with the as-cast conditions. Underaged T6 tempers display the best combination of properties, with high strength and reasonable fracture resistance. Importantly, T4 tempers for HPDC components typically display superior fracture resistance to permanent mould cast 356 alloy, for similar levels of tensile properties.

A range of alloy compositions that display extraordinarily rapid strengthening behaviour has also been identified. These high pressure diecasting alloys can be treated with a complete heat treatment cycle time of only 30 minutes and develop properties superior to conventional heat treated aluminium alloys requiring thermal cycles of up to 24 hours. This has major cost and particularly energy usage implications in manufacturing processes.

Significance of the new process for HPDC component applications
This new process significantly expands the range of applications in which HPDC components can be used, and allows HPDC components to be re-designed using lower amounts of metal to support the same levels of load. Heat-treated HPDC components (made from recycled metal) often have superior properties to sand cast and most permanent mould-cast aluminium alloys (made from primary metal), so substitution of these castings with a lower cost, heat-treated HPDC is also possible. The process also makes possible replacement of some wrought components, particularly when loaded in compression. The automotive sector is currently the biggest user of HPDC components, and the process is attractive to manufacturers of automotive components.

HPDC is considered the most cost-effective casting process for mass production. The cost of T6 heat treatment for a HPDC component has been quoted as being approximately half the cost of T6 heat treatment for a permanent mould or
sand cast product. Heat-treated HPDC components are thus substantially cheaper to produce than a heat-treated permanent mould casting or sand casting.

Reducing the amount of metal used per casting also has obvious cost benefits. If the tensile yield strength of a HPDC part is increased around 100%, then approximately 30% of the mass could be removed from the part, (taking into account design considerations, stiffness, castability etc). This means more re-designed components can be made per tonne of metal than was possible for the original design.

Designing a component with lower mass also has a substantial effect on productivity, die design and usage of consumables. As a result, the cost per part may be substantially reduced.

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