ULTALITE®—A low cost, lightweight aluminium metal matrix composite for braking applications

By Graham Withers, President, and Dr. Ren Zheng, Vice President Engineering, Cyco Group

ULTALITE® is a low cost aluminium metal matrix composite (AL-MMC) that uses ceramic particles extracted from flyash as the reinforcement particulate. Australian developed ULTALITE composites use ceramic particles to increase the wear resistance, provide high thermal conductivity, and give good machinability for metal components. The ceramic particles used are low cost because the flyash is sourced as a by-product of coal fired power plants.

The density of ULTALITE composites is about 2.3 g/cm³, or less than one third the density of gray cast iron. Components made from this material provide a weight saving of about 60% compared to similar cast iron parts and thus provide improved fuel efficiency with reduced green house emissions.

This attractive combination of properties and low cost makes ULTALITE AL-MMC an ideal material for the manufacture of wear resistant, lightweight automotive components such as brake drums, brake callipers, disc brake rotors, engine blocks, cylinder heads, transmission casings, and internal components such as pistons, connecting rods, oil pumps etc.

ULTALITE composites typically contain between 15% and 30% spherical ceramic particles. However, unlike other more expensive composites, ULTALITE uses inexpensive ceramic particles derived from flyash, a by-product of the power generation industry. It consists of inorganic, incombustible matter formed during the combustion of powdered coal in electric power generating plants, and consists mainly of SiO₂ and Al₂O₃, along with other extraneous impurities. The flyash material solidifies while suspended in the exhaust gasses, and forms as amorphous, spherical particles between 0.5 μm and 100 μm in size. Both hollow (cenospheres) and solid (precipitator) flyash particles are formed, but only the solid particles are used in the ULTALITE AL-MMC brake applications.

The Ash Development Association of Australia estimates that there are now about 13.5 million tonnes of ash produced a year, with about 3.7Mt (46%) put to beneficial use. The American Coal Ash Association has estimated that about 118 million tonnes of flyash is generated annually in the USA. Of this, about 31.3% is used in products such as concrete and road base, the remainder being disposed of in ash ponds or landfills. This means there is a substantial source of inexpensive ceramic particles available from flyash that can be used for ULTALITE AL-MMCs.

During the past 10 years, conventional metal matrix composites have been used in several automotive applications, including brake rotors and drums, pistons, cylinder liners and valves. Cars that have composite brake drums and rotors include the Lotus Elise and the Plymouth Prowler. Generally, composite brake drums and rotors have been limited to low volume, specialised applications, due to the high cost of the composite materials.

Conventional composite materials typically contain either Silicon Carbide (SiC) or Aluminium oxide (Al₂O₃) particles, which are considerably more expensive than the ceramic particles derived from flyash. In addition, conventional composites are typically produced from primary Aluminium, while ULTALITE composites can be produced using secondary alloys, which typically cost 15% to 20% less than primary alloys. Material costs exclusive of mixing and processing costs for ULTALITE composites are very favourable compared to conventional Al-SiC materials. The ULTALITE cost is calculated using secondary Aluminium prices, while the Al-SiC composites are normally fabricated using primary Aluminium alloys. Due to the low cost of flyash particles, the ULTALITE cost drops sharply with increasing reinforcement content, so at 30% ceramic content, the ULTALITE is less than 60% of the cost of conventional Al-SiC composites.

Johns Hopkins University’s Prof Bob Pond Snr was the first to suggest producing low cost composites by stirring particles into liquid Aluminium. That patent, together with other proprietary technology, is now controlled by Cyco Systems. Building on the relatively simple methods suggested by Pond and other researchers for stirring particles into molten Aluminium, Cyco Systems has recently made significant advances in the cleaning and classification of the ceramic particles, as well as identifying improved techniques for stirring the ceramic.
particles into the Aluminium. These techniques allow the production of lower cost and higher quality composites, and are described in the following sections of this paper.

**EXTRACTING CERAMIC PARTICLES FROM FLYASH**

Raw flyash contains a diverse mixture of materials, including a wide size range of hollow and solid particles, as well as other extraneous impurities, which need to be sorted so the desired ceramic particles can be extracted. Recently a beneficiation process developed by Prof. Thomas Robl and co-researchers at the University of Kentucky has been applied to the manufacture of ULTALITE® composites. Originally developed for the production of high grade pozzolan for concrete manufacturing, the classification and froth flotation techniques can also be used to extract the desirable ceramic particles from flyash. This proprietary pre-treatment has been tailored to eliminate the hollow particles, extract detrimental carbon based impurities and remove the extremely fine and coarse particles. All that remains are dense ceramic particles with an average particle size of approximately 30μm.

**STIRRING CERAMIC PARTICLES INTO MOLTEN ALUMINIUM**

Recent advances have also been made in the technology used to disperse the ceramic particles into molten Aluminium. The patented mixing process used is extremely efficient, provides good wetting between the Aluminium matrix and the ceramic particles, and allows stirring time to be kept relatively short.

The ceramic particles are introduced under the surface of the semi solid Aluminium by feeding through the internal passageway of a hollow impeller tube.

The lower end of the impeller tube contains teeth that produce a shear region in the molten Aluminium between the impeller base and head. The high shear forces created by the rotating impeller induce rapid wetting of the particles, resulting in a uniform distribution of ceramic particles throughout the melt. The short stirring time, together with the elimination of the fine (20 μm and smaller) flyash particles, minimizes the exothermic chemical reaction between the molten Aluminium alloy and the ceramic particles.

**CASTING BRAKE DRUMS**

The ULTALITE ingots can be re-melted for component casting. Due to the similarity in density between the solid ceramic particles and the molten Aluminium, stirring is not required to keep the ceramic particles well distributed in the molten Aluminium in the holding furnace.

Typically, squeeze casting is used to produce the near net shape components. Squeeze casting is a modified die casting process, using a vertical die casting machine, and hardened, re-usable steel dies. While conventional high pressure die casting can produce a large amount of harmful residual porosity in the finished castings (obviously unacceptable in a safety critical castings such as brake drums), squeeze casting uses much slower injection of the liquid alloy into the die, thereby avoiding the formation of gas porosity during the filling of the die cavity.
The ULTALITE AL-MMC brake drum (see figure 1) weighs 2.3 kg, less than half the weight of a conventional cast iron drum. The base alloy for this casting was Al-7% Si-2%Mg, and 20% ceramic particles were added to form the composite.

Cyco Systems has also redesigned brake drums, to exploit the properties of the ULTALITE composites. The venting built into this drum facilitates the high thermal conductivity of the AL-MMC to dissipate heat generated during braking 6.

Table 1 shows typical properties of squeeze cast ULTALITE composites, and compares them to handbook data for permanent mould A356-T6 and die cast 380. The figures show that ULTALITE composites have strengths similar to die cast 380, but significantly higher than the A356. Elongation of the ULTALITE composites is slightly lower than the die cast alloy, due to the ceramic reinforcement particles in the composite.

Testing of ULTALITE Drums

Recently dynamometer has been performed. Dynamometer testing of 8inch diameter ULTALITE brake drums, manufactured by the squeeze casting process, was performed at Brake Testing International (BTI), located in Hinckley, England. The test regime followed procedures laid out in SAE specification J25222. Standard off the shelf brake linings (Don #8259 and Nisshimbo) were used in all the tests.

A series of fade segment 6.9 tests for three lining combinations (cast iron + Nisshimbo, ULTALITE+ Nisshimbo and ULTALITE+ Don #8259) were conducted 7. The plots in the top graph, which show brake factor, temperature and applied pressure variations across 15 stops for an OE cast iron + Nisshimbo combination, were used as benchmarks.

![A vented brake drum designed to exploit the better thermal conductivity of the ULTALITE composites.](image)

**Properties of the ULTALITE Composites**

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<table>
<thead>
<tr>
<th>Material</th>
<th>Process</th>
<th>Percentage of Ceramic Particles</th>
<th>Yield Strength (ksi)</th>
<th>Tensile Strength (ksi)</th>
<th>Elongation (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ultalite-20H (T6)</td>
<td>Squeeze cast</td>
<td>20%</td>
<td>--</td>
<td>48</td>
<td>2.0</td>
</tr>
<tr>
<td>Ultalite-55 (T6)</td>
<td>Squeeze cast</td>
<td>5%</td>
<td>--</td>
<td>49</td>
<td>2.5</td>
</tr>
<tr>
<td>A356 (T6)</td>
<td>Permanent mould cast</td>
<td>0%</td>
<td>27</td>
<td>38</td>
<td>5.0</td>
</tr>
<tr>
<td>380</td>
<td>Die cast</td>
<td>0%</td>
<td>24</td>
<td>48</td>
<td>3.0</td>
</tr>
</tbody>
</table>

![Fade segment 6.9 results for three lining-drum combinations (CI = cast iron and UL = ULTALITE). Blue curve = brake factor, red = temperature changes and green = variations in the applied pressure.](image)
The data shows that the ULTALITE brake drum has higher brake factors. The average brake factors for all ULTALITE brake lining combinations was about 1.6 or above. The average brake factor for the cast iron drum was around 1.2. The temperature graph illustrates maximum temperature in the ULTALITE brake drums never exceeded 185°C with either lining, compared to a maximum temperature of over 300°C for the cast iron + Nisshimbo combination. This is due to the significantly higher thermal conductivity of Aluminium compared to cast iron, providing significantly better heat dissipation characteristics.

Dynamometer testing also revealed that overall lining wear was actually a little lower for the ULTALITE drums, even when compared to conventional cast iron drums. This testing with ULTALITE brake drums has shown that special brake linings are not required. In the past, excessive lining wear has been a problem with other composites brake drums, where lining wear has been so high as to require the use of special linings.

The extremely low lining wear of ULTALITE drums is probably a consequence of the spherical nature of the ceramic reinforcement particles used with ULTALITE composites. Other AL-MMC materials generally use angular ceramic reinforcement particles that can tear up the linings.

In addition, due to superior heat dissipation, the operating temperature of the ULTALITE brake drums was more than 100°C lower than that of the cast iron drums, thereby reducing brake fade. This data shows that the ULTALITE brake drum lining wear characteristics are equivalent to, or better than, those of a cast iron brake drum.

Cyco Systems continues to develop the technology of the ULTALITE composites for braking applications. The technology is available for licensing from Cyco Systems. For more information, visit www.ultalite.com.

Comparison of brake lining wear for cast iron and ULTALITE brake drums.