CDC CASTING

Cast-decant-cast is a low-cost method for the production of complex-shaped, functionally gradient components.

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The CDC (cast-decant-cast) process is designed for the production of functionally gradient materials. Near-net shape components are produced in a single-stage, three-step process based on conventional foundry technology that enables significantly greater shape flexibility than alternate methods.

Functionally gradient materials have a transition zone that exhibits smooth gradients in concentration, microstructure, and properties between the two metals (Fig. 1). However, current fabrication techniques limit components to thin coatings, small sizes, or simple shapes. In contrast, the CDC process is a low-cost alternative that produces FGMs by a simple casting approach that has few limitations on the shape or size of components.

This article describes the CDC process and shows several examples of material combinations and the products cast from them. In particular, it details the casting of a brake rotor made of functionally graded aluminum/aluminum-matrix composite.

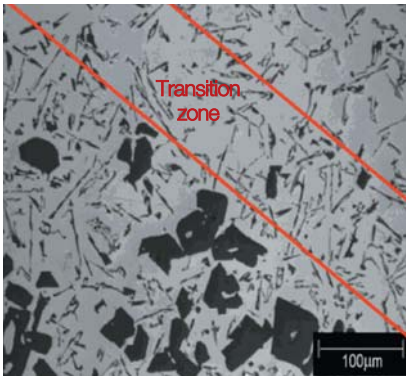

Fig. 1 — Microstructure of a functionally gradient material produced by the CDC process, showing aluminum alloy 390 in the lower left and alloy A356 in the upper right. The transition zone is about 150 µm thick.

Cast-decant-cast

The CDC process is essentially a three-step process that involves the simultaneous but separate melting of two alloys. In the first step, alloy A is poured into a mold, and a solid layer builds up from heat extraction through the mold walls. When the solid shell is at the specified thickness, the remaining central liquid is decanted back into the crucible.

Alloy B is then poured to fill the remaining cavity. If the appropriate level of superheat is chosen for alloy B, then a thin section at the surface of the shell of alloy A is re-melted, and the local alloying of the two metals prevents the formation of a discrete interface. Instead, a gradient in composition and microstructure forms between the two alloys, producing a functionally gradient material.

The CDC process has been adapted to a number of conventional casting methods, including several gravity and low-pressure casting technologies. The low-pressure technique for the CDC Process is based on an extension of low-pressure permanent mold casting, which allows FGM casting in a closed mold by means of counter-gravity filling to avoid melt turbulence.

As shown in Fig. 2, two crucibles are placed beneath the casting mold. A graphite block containing two barrel valves is situated between the crucibles and the mold. With barrel valve A open (above alloy A), and valve B closed (Fig. 2a), chamber A is pressurized, causing alloy A to rise through the tube and into the mold.

After the layer of alloy A has solidified, the gas pressure is removed, and the remaining liquid A

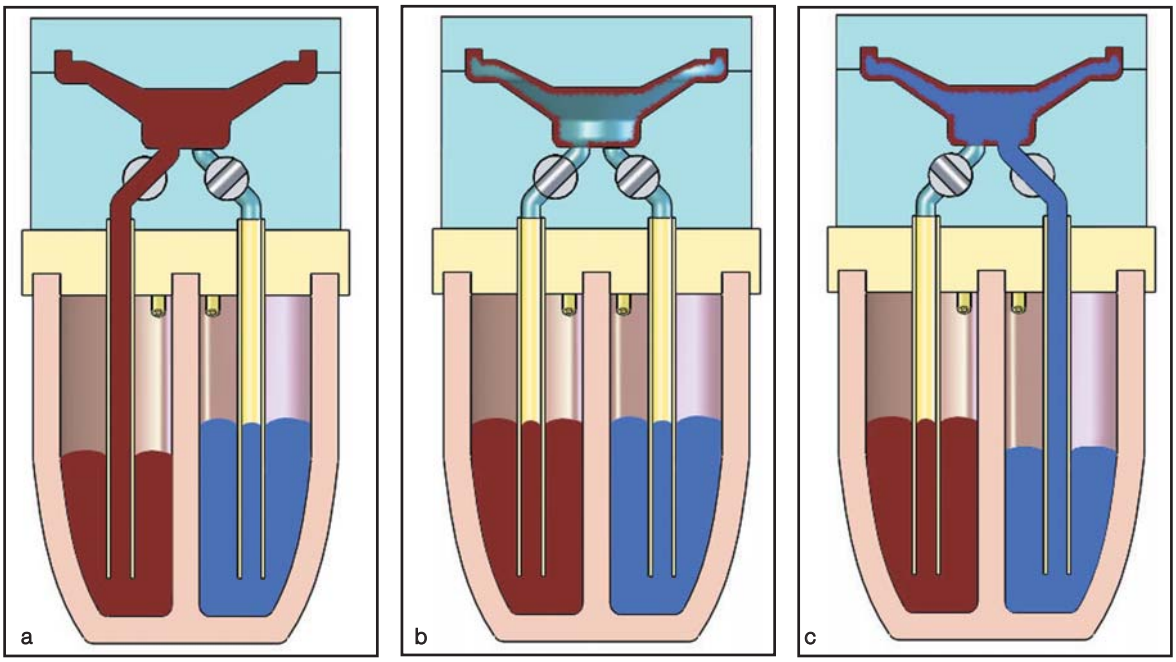

Fig. 2 — Low pressure apparatus and casting sequence for the CDC Process.

drops back into the crucible (Fig. 2b). Valve A is then closed and valve B opened. Gas pressure above the melt in chamber B forces the liquid alloy B up the graphite tube and into the mold, where it solidifies to form the functionally gradient material (Fig. 2c).

Alloy combinations

In addition to monolithic alloys, the CDC Process can combine a monolithic alloy and a composite. Figure 3 shows the microstructure of the gradient region between monolithic aluminum alloy A356 (Al-7Si-0.3Mg) and an aluminum metal matrix composite (Al-20 SiC). The transition zone between the two materials is about 1.5 mm thick. Other combinations include:

- **Aluminum and zinc:** Figure 4 shows the microstructure at the gradient region between aluminum alloy A356 (Al-7%Si-0.3Mg) and zinc alloy ZA-27 (Zn-27Al-2.25Cu). In this case, the transition zone is about 1 mm thick. Potential applications focus on reducing the weight of zinc components, and include lightweight bearings and lightweight non-sparking tools.
- **Aluminum and magnesium:** Initial trials combining aluminum and magnesium alloys have also shown promise. A material with a gradient from aluminum alloy 357 (Al-7-0.5Mg) to magnesium alloy AZ91D (Mg-9Al-0.7Zn-0.2Mn) has been achieved. Such magnesium + aluminum FGMs have huge potential in the transportation sector for cars and trucks.
- **Other materials**: No overriding technical reasons appear likely to prevent extending the CDC process to produce functionally gradient materials from higher melting-point materials such as copper alloys, steels, and even superalloys. However, development has been delayed as the Solidification Laboratory at University College Dublin does not have the capability to process high melting point alloys in the quantities required. However, trials at outside research facilities have been planned.

Brake rotors

The CDC process has been patented by University College Dublin and is available for licensing. Eck Industries, located in Manitowoc, Wisconsin, is a licensee of the process. Eck is a leading U.S. caster of aluminum alloys and metal matrix composites, and uses a variety of gravity and low-pressure processes.

Eck is working to produce aluminum brake rotors for mid-size truck applications. Although aluminum alloys are currently used in many automotive applications (wheels, engine blocks, cylinder heads), it is seldom applied in brake rotors. A key reason is the low wear resistance of most aluminum alloys, making them unsuitable for brake rotors. However, aluminum metal matrix composites do have sufficient wear resistance. They first appeared on production vehicles on the Lotus Elise, and later Eck Industries produced Al-MMC rotors for the Plymouth Prowler (Fig. 5).

However, for commercial trucking applications, the ductility and toughness of aluminum metal matrix composite rotors may be too low.

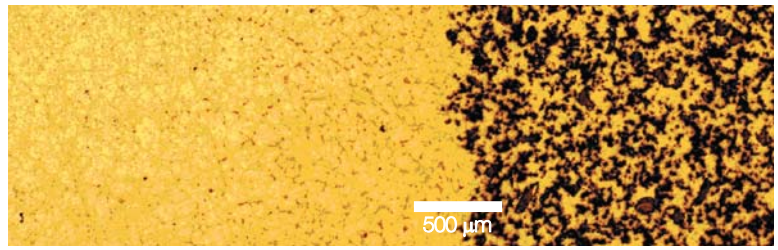

Fig. 3 — Functionally gradient material produced from an aluminum alloy A356 on the left and an aluminum metal matrix composite (F3S20S) on the right.

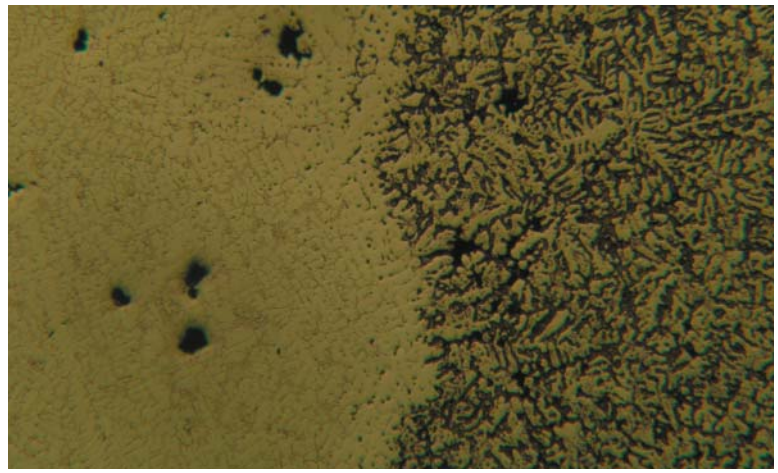

Fig. 4 — Functionally gradient material produced from an aluminum alloy A356 on the left and zinc alloy ZA-27 on the right.

Test rotors have been cast at University College Dublin in a sand mold from monolithic A356 and a Duralcan composite (F3S20S) by means of a gravity casting variant of the CDC process The basic brake rotor shape was modified from that of a conventional disk, with a reduced outer diameter to allow analysis of the optimum position of the runner system, and a deeper bell housing to facilitate investigation into the location of the gradient between the alloys (Fig. 6).

The test rotors showed a transition zone between the two alloys approximately halfway along the bell housing, with no discrete interface visible (the microstructure of the transition zone is shown in Fig. 4). The central part of the rotor that attaches to the wheel hub is composed of monolithic A356, while the outer part is composed of the Duralcan composite,

Fig. 5 — Aluminum metal matrix composite brake rotors produced by Eck Industries for the Plymouth Prowler.

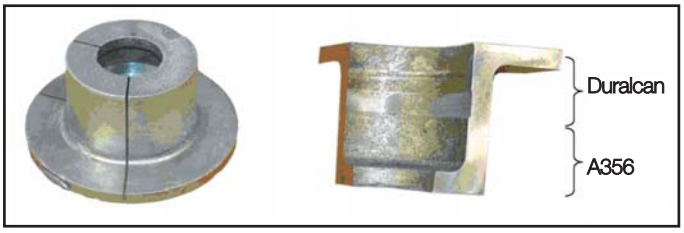

Fig. 6 — Prototype A356-Duralcan brake rotor produced using the CDC Process.

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to provide the wear resistance needed for the friction surfaces.

Eck Industries is now proceeding with the development of a commercial aluminum + composite brake rotor based on the CDC process.

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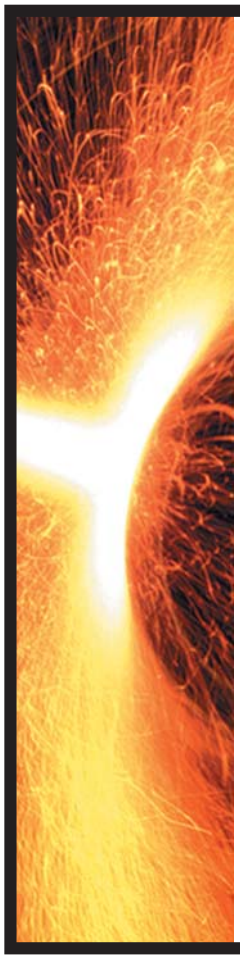

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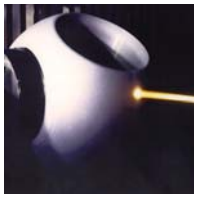

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