REPORT ON HIGH VOLUME FRACTION MMC VIA CENTRIFUGAL CASTING

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Background

Centrifugal casting of metal matrix composite rotors has demonstrated advantages over static pour or pressure pour of the composite. The most significant advantage is the movement of high performance particles where they are needed (braking surface) and away from the areas where they are a disadvantage (the rotor mounting surface). This leads to high toughness and greater fracture resistance in the highly stressed mounting area of the rotor. The higher yield of material poured to material sold reduces both remelt and cleaning costs. Since cost has been a significant impediment to the use of MMC's in rotor applications, cost reduction through the use of lower silicon carbide loadings in the melt stock that can still give an acceptable 20% loading on the braking surface, can make the use of these rotors more effective.

Successful centrifugal casting of aluminum MMC's has been demonstrated on a small scale. However, the means for large-scale economical production has not been developed. Problems involving control of die temperature because of die handling issues coupled with long cycle times has made the production of centrifugally cast MMC's suitable for only high cost, low volume applications.

Existing equipment is suitable for the casting of pipes and rollers in volume, but the unique problems of shape casting do not lend themselves to this equipment. Equipment for the centrifugal shape casting of conventional aluminum alloys in high volume has recently been developed.

Casting Trials

A semi-automatic casting machine designed to make aluminum castings was set up with the tooling for a 450 mm truck rotor. Samples were poured from 6061 material to insure working order of the machine and to assess preliminary settings for best casting quality. The rotors all showed hot tearing at the transition from thick to thin section.

20% SiC reinforced 359 alloy was melted in preparation for casting. The researchers believed that the hot tearing was the result of a feeding issue with the 6061 material. Previous experience in the static casting of the composite led us to believe that less shrinkage would occur with the MMC since the material contains 20% solids.

Figure 1 Rotor Showing Section Differences (6061 Material)

A number of castings were produced using various RPM's on the casting machine. The equipment is capable of multi-stage operation and some rotors were produced using multiple speeds and acceleration rates.

	Stage 1 RPM	Stage 2 RPM
#1	350	
#2	600	
#3	600	
#4	600	
#5	600	800
#6	600	625
#7	600	625

All rotors produced showed extensive hot tearing.

Figure 3 Composite Rotor Showing Hot Tearing

A casting currently produced by centrifugal casting was poured from composite material. The casting was chosen since the geometry was not prone to hot tearing and had been successfully produced in standard alloys.

A number of castings were made so the effect of RPM on distribution of the composite could be determined.

Figure 4 Sample Castings Poured From Composite

The gating was modified on the rotor tooling to determine whether the hot tear could be fed. Hot tears persisted under a wide range of operating parameters.

Sample rotors were ultrasonically tested to determine the extent of particle distribution of rotors already made. Rotors poured at 625 RPM demonstrated gradual distribution of SiC through the braking surface, while those poured at 800 RPM showed a sharp distribution variance at the edge of the braking surface.

Subsequent Trials

Rotors were poured with 359 20% SiC material modified by the addition of Si to a level of 12.5%. Those rotors poured did not exhibit hot tearing and were sent out for machining and testing.

Machining Operations

Problems were noted during machining due to the variability of SiC loading in the rotor as well as significant porosity in some of the rotors. Nonetheless, two good rotors were produced to dimension, with minimal porosity.

Figure 6 Rotor with Modified Si Content Showing No Hot Tearing

Testing For Particle Loading

Six rotors from the final machined batch of rotors were checked for particle loading. Location A was at the machined ID of the rotor, location B, 2” outboard of the ID, location C, 4” outboard of the ID and location D at the edge of the rotor. Particle loading determined from ultrasonic testing was as follows:

Location A	20.95%
Location B	24.76%
Location C	26.94%
Location D	30.22%

OEM Testing

A number of rotors showing minimal porosity were submitted to a brake equipment manufacturer for testing. The parts failed testing at the 50 mph stop due to problems with the friction couple. The severe grooving of the pad confirms a mismatch between the pad material and the SiC reinforced rotor. Low retardation during stop confirms that conclusion. Further development would be required to resolve this issue.

Cost Issues

The forces applied during centrifugal casting create intimate contact between the molten metal and the die surface. This reduces solidification and cycle time. This large truck rotor was produced at the same cycle time (7 minutes) as the much smaller Chrysler Prowler rotor produced in permanent mold from the same material. If the particulate could be better distributed to the braking surface only, machining cost could be reduced as well. It may be possible to start with a composite of a lower initial SiC level, thereby reducing the cost of the starting composite.

Conclusions

The porosity in most of these samples was related to the way the material was introduced into the mold, not the centrifugal casting process itself. Introduction through some sort of a tapered pouring sprue would be a possible solution. In theory, the rate of spin on the mold should have been higher to get better distribution of the particulate. While the machine was capable of higher RPM, the mold-closing device was not capable of holding the mold closed at higher speeds. Any additional work with parts of this size would require a modified mold-closing device. The testing done demonstrated the need for research into the friction couple between the pad and the rotor. Some work on this has been done, but the brake manufacturer was unable to procure pads in the required geometry for testing. In spite of the casting porosity and the high loads imposed in testing at stops of up to 80 MPH, the rotor did not fail, indicating that the material has adequate structural strength for the application.