5. JOINING

A. Die-Cast Net-Shaped Hole Process Development for Application of Thread-Forming Fasteners

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Objective

- Evaluate the effect of casting variation on clamp load and serviceability when using thread-forming fasteners in die-cast net-shaped holes of aluminum and magnesium alloys.
- Collect in-field data on casting-die hole features and pins during production operations at casting suppliers.

Approach

- Evaluate the effect of hole size and shape variation on clamp load when using a variety of thread-forming fasteners (TFFs) in die-cast net-shaped holes in Al and Mg alloys.
- Evaluate the reusability performance of a variety of TFFs in Al- and Mg-alloy die-cast net-shaped holes when subjected to repeated assembly/disassembly of a single fastener into the same hole.
- Evaluate the extent to which contamination in the form of debris is produced when inserting TFFs into Al- and Mg-alloy die-cast net-shaped holes.
- Collect in-field measurements of the variation in size, shape, and position of casting-die hole features and pins from automotive casting suppliers.

Accomplishments

- Completed testing to evaluate the effect of the hole size and shape when using three different TFF designs in Mg alloy AZ91D and a second TFF design (ALtracs®) in Al alloy A380. Testing of TAPTITE 2000® SP™ fasteners in A380 is also complete and results previously reported.
- Completed testing to evaluate the reusability performance of two TFF designs in Al alloy A380 and four TFF designs in Mg alloy AZ91D.
- Completed an evaluation of contamination created during the sequence of assembly/disassembly of TFFs into die-cast nut specimens of Al alloy A380 and Mg alloy AZ91D.
- Collected in-field measurements from automotive casting suppliers showing minimal variation in casting-die hole features and pins during production operations.

Future Direction

- Objectives for this project have been completed. Project participants are actively seeking a manufacturing demonstration project wherein die-cast net-shaped holes could be used to establish production experience of this capability.

Introduction

The focus of this technical-feasibility project was on resolving the highest priority technical challenges associated with application of thread-forming fasteners (TFFs) into die-cast, net-shaped holes in aluminum (Al) and magnesium (Mg) alloys, identified during the initial concept feasibility project completed in 2003. The priority issues were grouped into four technical challenges: (a) casting variation, (b) fastener design, (c) assembly processing, and (d) in-service requirements. The major facets of casting variation are cast hole size, shape, and position, resulting from the thermal, mechanical and metallurgical effects of the die-casting process. Fastener testing is complete to evaluate the effect of hole size and shape on clamp load. The closely related in-service issues of contamination and reusability were also evaluated via fastener testing. In addition, in-field data were collected from casting suppliers on die-pin wear and degradation. A variety of fastener designs, provided by the fastener suppliers, and assembly procedures, were evaluated during the testing. All of the prioritized issues were addressed for both Al alloy A380 and Mg alloy AZ91D during the Phase 1 technical-feasibility project.

Background

Progress has been made in applying TFFs into machined or stamped holes featured in steel automotive applications for general assembly. Use of these fasteners has eliminated the tapping operation, which reduced costs, investment, and improved warranty, while delivering better joint properties within an assembly. Opportunities exist to reduce costs. By using TFFs with net-shaped holes in lightweight castings, the drilling operation and associated equipment investment is eliminated without sacrificing joint performance. Potential applications for using TFFs in cast components are numerous and include powertrain (transmissions, engines, and rear axles), chassis, (control arms, suspensions) and body structures that utilize large castings (inner doors, lift gates, under-hood attachments and supports). Expanding the use of lightweight materials is the driver behind this project. Progress in applying the concept to Al castings has been minimal and even less with Mg. Successful development of this idea in cast products will expand the use of lightweight materials due to the proven benefits already achieved in the existing applications.

Approach to Hole Size and Shape Variation Testing

Holes in die castings are created by the use of steel pins inserted in specific locations in the die block. The potential exists for the dimensions of the die pin to change in size (diameter), or shape (taper), because of the repeated contact with the molten metal filling the die cavity. Molten Al tends to dissolve some alloy constituents of the steel and this dissolution is a function of temperature. Thus, if dissolution were to occur, it would be most prevalent at the leading end of the pin, which is the hottest, due to the large die block acting as a heat sink. In addition, exposure to molten Al and Mg can result in soldering of the alloys onto the pin, which is then cleaned with an Emory cloth. Repeated application of this mechanical cleaning process can result in further removal of pin material, thereby changing the diameter of the pin. Both of these changes, in time, have the potential to cause variation in the desired size and shape of the resulting hole in the die casting. The purpose of this hole-size and -shape test matrix was to determine the impact of variations from nominal hole size (diameter) and shape (taper) on the resulting clamp load, when using a TFF. The matrix for this testing includes three different tapers and up to three increments of larger and smaller hole diameters.

Clamp load was determined using the LabMaster Fastener Evaluation Test Cell. The nut-runner was programmed to drive the fasteners to failure and the Labmaster software recorded clamp load, input torque, and failure torque versus time and angular rotations of the fastener for each test. The failure mode was noted at the end of the test (break the fastener or strip the threads). Thirty tests, each combination, have already been completed and reported for TAPTITE 2000® SP™ fasteners in A380. Testing was completed at each combination of size and shape for ALtracs® coated with Magni 565 in Al alloy A380 and for ALtracs®, Mag-form®, and Remform® F, all coated with ZinKlad in Mg alloy AZ91D.

Results for Holes Size and Shape Variation Testing

PNNL completed 15 tests at each combination of size and shape for each fastener design in Mg alloy AZ91D. Torque-tension testing was completed for the ALtracs®, Mag-form® and Remform® F in Mg. The ALtracs® fastener shows minimal effect of size or shape on resulting clamp load at failure of the fastener, except for the 0.5° hole with the largest diameter where some fasteners stripped, as shown in Figure 1.

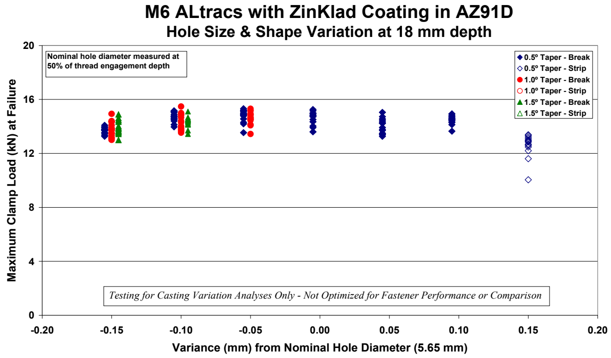


Figure 1. Torque-tension test results for size and shape matrix using ALtracs® in AZ91D.

The Mag-Form® showed a consistent clamp load over the range of size or shape variation, with similar data presented in Figure 2. The Remform® F fastener shows a minimal effect of size and shape on most combinations of size and shape; however, a broad range of clamp load was observed at the smallest hole size.

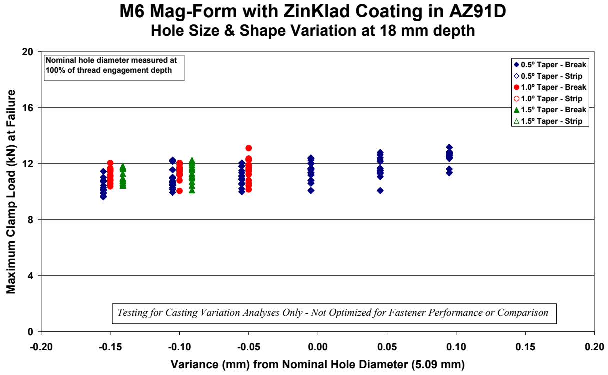


Figure 2. Torque-tension test results for size and shape matrix using Mag-Form® in AZ91D.

Approach to TFF Reusability Testing

The reusability test evaluated the capability of a fastener to maintain clamp load after repeated installation of the same fastener into the same hole. To achieve this, the clamp load, at a target input torque, was measured for 14 consecutive rundowns of a single fastener into a die-cast nut specimen. For a given fastener design, the target input torque was experimentally determined to be the torque required to generate 9 kN of clamp load. This clamp-load target was also established experimentally as the load generated by installing a machine screw at 11 Nm of input torque, which is a common assembly specification range (10-12 Nm) for M6 fasteners. After 14 consecutive rundowns, the torque limit was removed and the fastener tested to failure. Clamp load and input torque at failure, as well as the failure mode, were recorded to conclude the test.

Results for Reusability Testing

Reusability testing was completed for TAPTITE 2000® SP™ and ALtracs® fasteners coated with Magni 565 in Al alloy A380. Three hole shapes were evaluated for each fastener and include: 1.0° taper, 0.5° taper and 0° taper (drilled hole) for comparison. Figure 3 shows the average of the clamp load and corresponding input torque for a total of 15 tests conducted using the ALtracs® fastener at each of the three hole shapes (1.0°, 0.5° and 0.0°). Clamp-load retention is 100% after 14 rundowns of the same fastener and the same hole and the fastener broke in all cases on the 15th rundown with no torque limit. These results indicated no change in clamp-load magnitude or retention over the range of hole shapes tested.

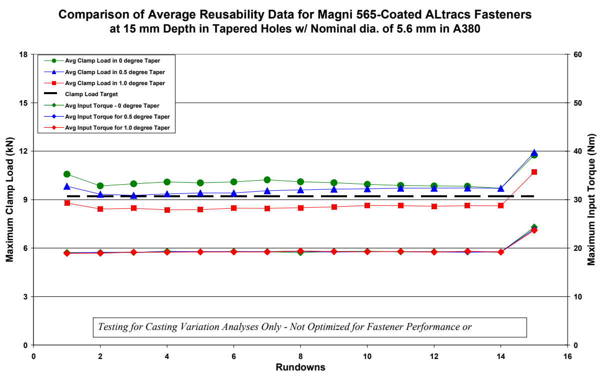


Figure 3. Reusability results for a range of hole shapes (taper) using ALtracs® fasteners in A380.

For Mg alloy AZ91D, reusability testing was completed for ALtracs®, Mag-form®, Magtite®, and Remform® F all coated with ZinKlad. Similar to the Al alloy, three hole shapes were evaluated for each fastener 1.0°, 0.5° and 0° tapers. Figure 4 shows average reusability data for the Magtite® design. Clamp-load retention for this fastener is nearly 100% and the fastener broke in all cases on the 15th rundown with no torque limit. Similar results were achieved for the ALtracs®, Mag-Form® and Remform® F designs in AZ91D with nearly 100% clamp-load retention at breaking of the fastener when tested to failure.

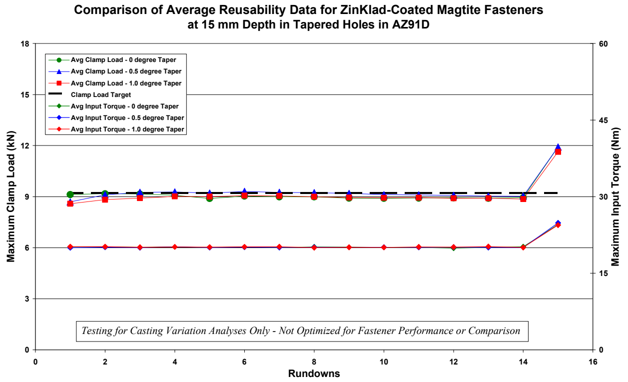


Figure 4. Reusability results for a range of hole shapes (taper) using Magtite® fasteners in AZ91D.

Approach to TFF Contamination Testing

PNNL investigated the extent to which contamination in the form of debris is generated while using TFFs in Al- and Mg-alloy die-cast net-shaped holes during this technical-feasibility project. The approach to this test was to collect and weigh any debris generated during installation of the fastener during the reusability test. Debris was cumulatively weighed using an electronic balance after the 1st, 2nd and 5th rundowns. Samples of collected debris were analyzed using a scanning electron microscope (SEM) equipped with an energy-dispersive spectrometry (EDS) detector to determine the composition of the debris collected.

Results for TFF Contamination Testing

Debris was collected during six reusability tests for TAPTITE 2000® SP™ and ALtracs® fasteners for each of the 1.0°, 0.5°, and 0° tapers, and for three machine screws in tapped holes. All fasteners were coated with Magni 565. Both TFFs generated measurable amounts of debris with drilled holes generating slightly more debris, in each case, as shown in Figure 5. The machine screw generated minimal amounts of debris during the sequence of rundowns.

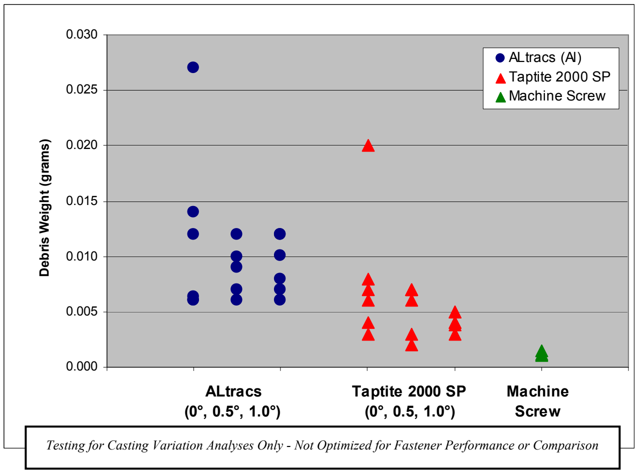


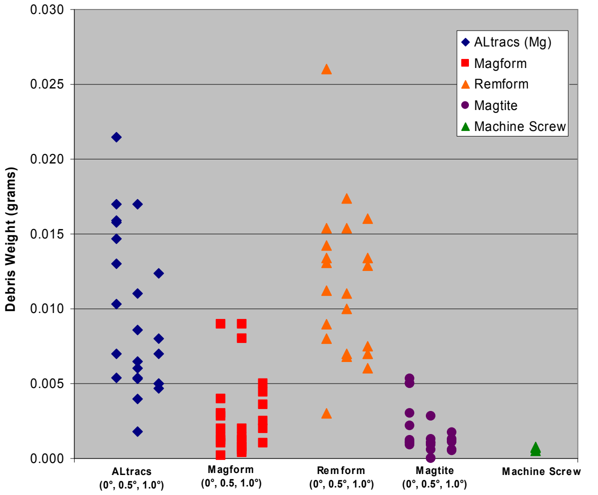
Figure 5. Contamination results for a range of hole shapes (taper) TAPTITE 2000® SPTM and ALtracs® fasteners in A380.

SEM analysis of samples of the debris showed that, in both cases, the debris composition matched the A380 alloy, with small amounts of coating deposits smeared on some pieces of debris. For the AZ91D alloy, debris was also collected during nine reusability tests, for ALtracs®, Mag-Form®, Remform® F and Magtite® fasteners, all coated with ZinKlad coating, for each of the 1.0°, 0.5° and 0° tapers, and for three machine screws in tapped holes. Figure 6 shows the amount of debris collected from these five fasteners. The ALtracs®, Mag-Form®, and Remform® F fasteners showed measurable amounts of debris, with drilled holes generating slightly more debris in each case. The Magtite® fasteners and machine screws generated minimal amounts of debris during the sequence of rundowns.

SEM analysis of samples of the debris showed that, in all cases, the debris composition matched the AZ91D alloy, with small amounts of coating deposits smeared on some pieces of debris.

Approach to TFF In-Field Casting Variation Data

In-field data from various casting suppliers was collected to analyze and determine capability, and to identify practices for achieving minimal variation in size, shape, and position of as-cast holes. Hole-position data were measured daily on selected castings.



Testing for Casting Variation Analyses Only - Not Optimized for Fastener Performance or Comparison

Figure 6. Contamination results for a range of hole shapes (taper) ALtracs®, Mag-Form®, Remform® F, and Magtite® fasteners in AZ91D.

Results for In-Field Casting Variation Data

In-field data were collected from automotive casting suppliers for analysis and comparison to laboratory test data. The in-field data and laboratory test-cell data were compared to identify best practices and to determine gaps for further technical development.

Instead of measuring actual cast holes, the approach selected was to measure the core pins that made the holes. Core pins were measured before dies were put back into service from major maintenance overhauls. Most dies are taken out of service every 20,000 to 40,000 cycles for routine maintenance and core-pin replacement. The same core pins were removed and measured, after the dies were removed from service, for the next major maintenance overhaul. Three typical automotive casting dies were included in the study, ranging in size from a pump-body casting, a transfer-case casting, to a transmission-case casting.

Figure 7 shows the measurements from the pump body casting. The pins were in service for 29,724 shots and experienced a maximum dimensional change of 0.05 mm.

Pump Body after 29,724 shots

PIN #	LOCATION	ORIG. DIA.	FINAL DIA.	VARIATION	
5	A	0.267 inch.	0.267 inch.	0.000 inch.	0.00 mm
	B	0.226 inch.	0.228 inch.	0.002 inch.	0.05 mm
	C	0.204 inch.	0.206 inch.	0.002 inch.	0.05 mm
6	A	0.267 inch.	0.267 inch.	0.000 inch.	0.00 mm
	B	0.227 inch.	0.228 inch.	0.001 inch.	0.025 mm
	C	0.204 inch.	0.206 inch.	0.002 inch.	0.05 mm

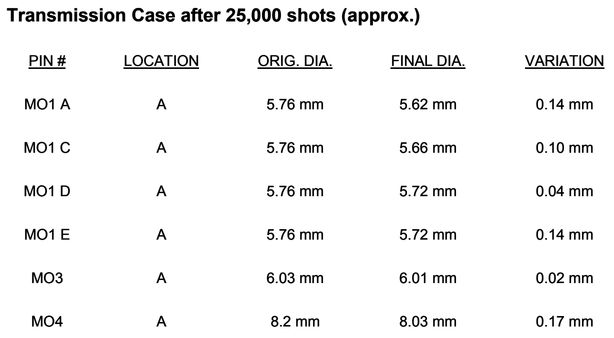
Figure 7. Diameter measurements from pump body casting die before and after 29,724 shots.

Figure 8 shows the measurements from the transfer-case casting. The pins were in service for 23,108 shots and experienced a maximum dimensional change of 0.025 mm. Figure 9 shows the measurements from the transmission-case casting. The pins were in service for approximately 25,000 shots and experienced a maximum dimensional change of 0.17 mm.

Transfer Case after 23,108 shots

PIN #	LOCATION	ORIG. DIA.	FINAL DIA.	VARIATION	
8	A	0.299 inch.	0.298 inch.	0.001 inch.	0.025 mm
	B	0.287 inch.	0.287 inch.	0.000 inch.	0.00 mm
17	A	0.298 inch.	0.298 inch.	0.000 inch.	0.00 mm
	B	0.288 inch.	0.289 inch.	0.001 inch.	0.025 mm

Figure 8. Diameter measurements from transfer case casting die before and after 23,108 shots.

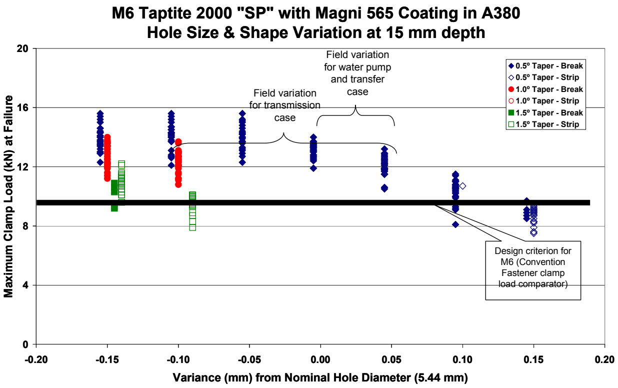


Transmission Case after 25,000 shots (approx.)

PIN #	LOCATION	ORIG. DIA.	FINAL DIA.	VARIATION
MO1 A	A	5.76 mm	5.62 mm	0.14 mm
MO1 C	A	5.76 mm	5.66 mm	0.10 mm
MO1 D	A	5.76 mm	5.72 mm	0.04 mm
MO1 E	A	5.76 mm	5.72 mm	0.14 mm
MO3	A	6.03 mm	6.01 mm	0.02 mm
MO4	A	8.2 mm	8.03 mm	0.17 mm

Figure 9. Diameter measurements from transfer case casting die before and after ~25,000 shots.

These results were overlaid onto the laboratory results for the TAPTITE 2000® SP™, as shown in Figure 10. As can be seen, the entire set of clamp load outputs under the range of dimensional variation from the core pins are all well above the 9 kN level, which is the design criterion for an M6 fastener. Therefore, it is reasonable to conclude that, based on comparison of available field measurements and laboratory clamp-load tests, it is probable that for properly sized core pins, variation in hole size and shape can provide acceptable clamp loads over the entire maintenance cycle of the core pins <u>without additional cost or effort over the existing process.</u>



Testing for casting variation analysis only – not optimized for fastener performance or comparison.

Figure 10. Comparison of size and shape testing to in-field casting measurements.

In-field hole position data were collected from the quality system for two castings. Hole position is important because variation in hole position, which results in any amount of shadowing of mating holes, will affect the installation of the fastener. As part of the routine quality inspection process, at least one casting, per shift, per die cavity was measured on a coordinate measuring machine to verify all dimensions are within specification. The position data for a selected cast hole in the pump-body casting and in the transfer- case casting were provided for our analysis during the time frame the shape and size core-pin study was underway. The data provided were hole positions from datum lines in two planes.

The analyses of the dimensional data provided yielded the following results:

<u>Surface</u>	<u>Min.</u>	<u>Max.</u>	<u>Total Var.</u>
<u>Pump Body</u>			
X Dimension	0.037 mm	0.50 mm	0.46 mm
Y Dimension	92.12 mm	92.4 mm	0.20 mm
<u>Transfer Case</u>			
X Dimension	6.2 mm	6.4 mm	0.20 mm
Y Dimension	151.1 mm	151.2 mm	0.10 mm

The adequacy of cast hole position capability will ultimately be determined by the product design requirements and the designers ability to accommodate the position variation in the specific application.

Conclusions

This technical-feasibility project has aimed to resolve the highest-priority issues associated with applying thread-forming fasteners in die-cast net-shaped holes in lightweight alloy castings. The fastener testing results and in-field casting variation measurements can be coupled together to conclude that indeed capability exists to use thread-forming fasteners in as-cast components currently in production today. We assessed this capability using a variety of fastener designs, in both aluminum and magnesium die-casting alloys and by assessing the variation in components produced by multiple casting suppliers.

Future Work

We completed all work on this project. Project participants are actively seeking a manufacturing demonstration project wherein die-cast net-shaped holes could be used to establish production experience of this capability.

Publications

"*Application of Thread-Forming Fasteners in Net-Shaped Cast Holes in Lightweight Metal Alloys,*" D.M. Paxton, G.J. Dudder, W.C. Charron, T.H. Cleaver, TMS Letters: Lightweight Materials, 2006.

Presentations

"*Application of Thread-Forming Fasteners in Net-Shaped Cast Holes in Lightweight Metal Alloys,*" D.M. Paxton, G.J. Dudder, W.C. Charron, T.H. Cleaver, at the TMS Symposium on Lightweight Materials, March 16, 2006.

"*Use of Thread-Forming Fasteners in Lightweight Alloy Die-Cast Net-Shaped Holes,*" D.M. Paxton, G.J. Dudder, W.A. Charron, T.H. Cleaver, at THERMEC' 2006: International Conference on Processing & Manufacturing of Advanced Materials, July 3-6, 2006.