5. JOINING

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

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Contractor: Pacific Northwest National Laboratory / U.S. Automotive Materials Partnership
Contract No: DE-AC06-76RLO 1830 / FC26-02OR22910

Objectives

- Evaluate the effect of hole size and shape variation on clamp load using thread-forming fasteners (TFFs) in aluminum alloy die castings.
- Evaluate the reusability performance of thread-forming fasteners in aluminum die castings 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 aluminum die-cast net-shaped holes at 3-diameter thread engagement.
- Identify automotive casting suppliers and collect in-field measurements of variation in size and shape of casting-die hole features and pins.

Accomplishments

- Completed testing and evaluation of the effect of hole size and shape variation on clamp load when using TFFs in aluminum alloy die castings.
- Implemented a test plan recommended by the USCAR Fastener Committee to evaluate the requirements for reusability when assembling TFFs in die-cast net-shaped holes.
- Completed initial reusability testing of selected TFFs in aluminum alloy die-cast net-shaped holes.

- Completed an initial assessment of contamination created during the sequence of assembly/disassembly of TFFs into aluminum die-cast nut specimens at 3-diameter thread engagement.
- Initiated the collection of in-field data from casting suppliers who are taking measurements of hole size, shape, and position variation during production casting operations.

Future Direction

- Execute remaining reusability tests of additional TFFs in aluminum alloy die castings.
- Execute hole size and shape testing of TFFs in magnesium alloy die castings.
- Execute reusability testing of TFFs in magnesium alloy die castings.
- Execute next phase of serviceability, debris, and hole size and shape testing using magnesium specimens.
- Analyze in-field measurement data collected by casting suppliers taking measurements of hole size, shape and position variation during production casting operations.

Introduction

This technical feasibility project is focused on resolving the highest priority technical challenges associated with application of thread-forming fasteners (TFFs) into die-cast, net-shaped holes in aluminum and magnesium alloys which were identified during the initial concept feasibility project completed in 2003. Those priority issues were grouped into 4 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 position, shape and size resulting from the thermal, mechanical and metallurgical effects of the die-casting process. Fastener testing is planned to evaluate the effect of hole size, shape and position on clamp load. In addition, in-field data is being collected from casting suppliers on die-pin wear and degradation. A variety of fastener designs provided by the fastener suppliers and assembly procedures will be evaluated during this testing. Also to be considered in this phase is the closely related in-service issues of contamination and reusability. All of these prioritized issues will be addressed for both aluminum and magnesium alloys during the Phase 1 technical feasibility project.

Background

Progress has been made in applying TFFs into machined or stamped holes featured in automotive applications for general assembly. Use of these fasteners has eliminated the tapping operation and thereby reduced costs, reduced investment, and improved warranty while delivering better joint properties within an assembly.

Opportunities exist to further reduce costs by using TFFs with net-shaped holes in lightweight castings by eliminating the drilling operation and associated equipment investment 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, liftgates, under-hood attachments and supports). Expanding the use of lightweight materials is the driver behind this project. Little progress has been made in applying this concept to aluminum castings and even less progress has been made with magnesium. Successful development of this idea in cast products will expand the use of lightweight materials due to the proven benefits already achieved in the "as-stamped" 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) resulting from repeated contact with the molten metal filling the die cavity. Molten aluminum 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 aluminum and magnesium can result in soldering of these 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 is to determine the impact of variations from nominal hole size (diameter) and shape (taper) on the resulting clamp load when using a thread-forming fastener. The matrix for this testing includes three different tapers and up to three increments of larger and smaller hole diameters and is presented in Figure 1. The nominal hole for a M6 Taptite 2000 fastener has a 0.5 degree taper with a hole diameter of 5.44 mm at the target thread engagement depth of 15 mm. The variations in size and shape are made relative to this nominal definition. Test plates with a range of hole sizes and shapes were cast from aluminum alloy A380 and machined into individual test specimens as shown in Figure 2.

Clamp load was determined using the LabMaster Fastener Evaluation Test Cell. This unit utilizes a slide-bearing mount for the fastener drive system and mounting for the rotary torque-angle sensor and torque-tension research head. The fastener test system couples with a DC electric nut-runner tool and controller, a rotary torque-angle transducer, a combination thread-torque and clamp-force transducer, and a computer control system for accurate test reproduction and data logging and reporting. The test-stand equipment and Bosch Rexroth nut-runner are shown in Figure 3. The nut-runner was programmed to drive the fasteners to failure at a rundown speed of 240 RPM 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). The fasteners for these tests were coated with Magni 565 and a total of 30 tests were run at each combination of size and shape.

Results for Holes Size and Shape Variation Testing

Clamp load at failure and mode of failure are plotted vs. hole size in Figure 4. As shown in the test matrix, the nominal taper (0.5 degree) was tested at three (0.05 mm) increments above nominal (5.44 mm) and three increments below nominal. At nominal diameter, the average maximum clamp load was 13 Nm and the failure mode in all cases was breaking the fastener. As the hole diameter increased by 0.05 mm, the clamp load decreased to 12 Nm and the failure mode in all cases remained breaking the fastener. As the hole size increased to the next two increments (+0.10 mm and +0.15 mm), the average clamp load continued to decrease to 10 Nm and 9 Nm respectively, and fastener stripping became more prevalent with the larger holes. For hole diameters at nominal +0.10 mm, 1 in 30 fasteners stripped, whereas for hose holes at nominal + 0.15 mm, the failure mode for 15 of the 30 tests was stripping. For the same 0.5- degree taper with hole sizes smaller than nominal, the average clamp load was 14 Nm for all three increments and the failure mode for all cases was breaking the fastener. However, the standard deviation for these three sizes was 2 Nm and the clamp load in all tests fell in the range from 12-16 Nm, whereas the standard deviation at the nominal diameter was 1 Nm and all tests resulted in clamp loads ranging from 12 to 14 Nm. This maybe be indicative of excessive galling of the fastener and would result in poor reusability.

Nominal = 5.44 mm	Nominal - 0.15 mm	Nominal - 0.10 mm	Nominal - 0.05 mm	Nominal	Nominal + 0.05 mm	Nominal + 0.10 mm	Nominal + 0.15 mm
0.5º Taper	X	X	X	X	X	X	X
1.0º Taper	X	X	X				
1.5º Taper	X	X					

Figure 1. Test matrix for hole size and shape variation testing in aluminum alloy A380.

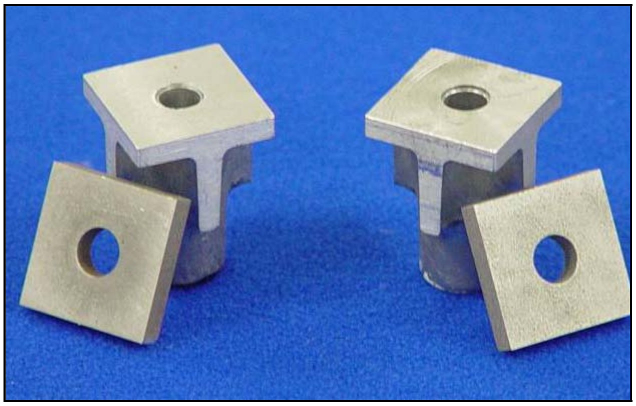

Figure 2. As-cast aluminum nut and washer specimens used for thread-forming fastener torque-tension mechanical testing.

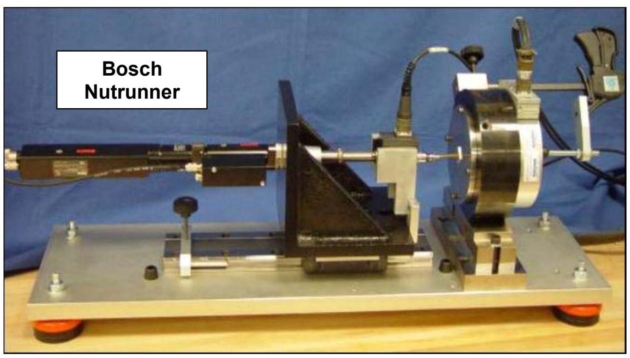

Figure 3. LabMaster Fastener Evaluation Test Cell from RS Technologies with integrated Bosch nutrunner.

In the case of the 1.0-degree taper, three increments below nominal were tested and resulted in average clamp loads increasing from 11.8 Nm at nominal -0.05 mm to 13 Nm at nominal -0.15 mm. For the largest of these holes, 3 out of 30 tests resulted in failure modes of fastener stripping. As the hole diameter decreased, all failure modes were breaking the fastener. Similar to the smaller holes at 0.5 degree taper, the standard deviation in these tests was approximately twice (2 Nm) observed at the 0.5 degree taper hole with nominal diameter (1 Nm). For those holes at the largest taper (1.5 degree), only 2 hole diameters were tested and both resulted in high probability of stripping, i.e. 30/30 at nominal -0.10 mm and 25/30 for the smaller hole at nominal -0.15 mm.

Results from this size and shape test matrix suggest that clamp load performance of nominal hole sizes for 0.5-degree tapered holes is most comparable to hole size of nominal + 0.05 mm. For larger holes, the probability of fastener stripping increases and the clamp load decreases. For 0.5-degree tapered holes smaller than nominal diameter (5.44 mm), the variability in clamp load is almost twice that observed at nominal conditions. The high probability of fastener stripping in both the larger tapered holes indicates this feature is likely limiting in hole geometry.

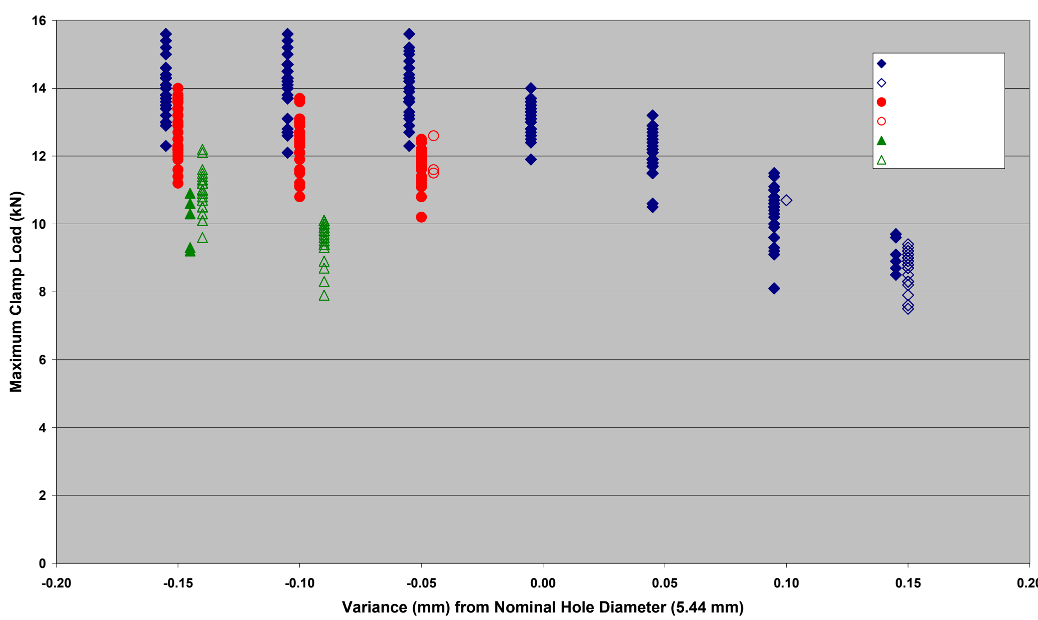

Figure 4. Clamp-load test data for hole size and shape variation test matrix using Taptite with Magni 565 coating at 15 mm thread-engagement depth.

Approach to TFF Reusability Testing

In order to establish a test procedure that would adequately address the issues associated with reusability, the project team requested input from the USCAR Fastener Committee which consists of OEM representatives with expertise in fastener technology and assembly applications. This committee prepared a recommended test procedure to assess reusability performance. This procedure was adopted by the project team and is presented in Figure 5. After initial testing and based on discussions with the Project Fastener Team, the procedure was modified such that the target torque was determined to be the assembly specification torque used to install M6 fasteners on the assembly line, the range of which is 10-12 Nm. With this established, a machine screw was assembled into a tapped hole to a target input torque of 11 Nm and the resulting clamp load recorded. This sequence was repeated 13 more times for a total of 14 consecutive run-downs. On the 15^{th} run-down, the torque limit was removed and the joint was tightened to failure of the fastener. Similar testing was repeated for both the Taptite and ALtracs thread-forming fasteners. The nut-runner was programmed to drive the fasteners to target torque at a rundown speed of 240 RPM and the Labmaster software recorded clamp load, input torque versus time and angular rotations of the fastener for each test. The fasteners for these tests were coated with Magni 565 and a total of 10-15 tests were run at each combination of size and shape.

Results of Reusability Testing

The clamp-load and input torque data for a series of 15 reusability tests using M6 machine screws is presented in Figure 6. The clamp load achieved was ~10 Nm and clamp-load retention was nearly 100% when running the same machine screw into the same hole 14 times. The average data were very repeatable for the 15 fasteners and nut specimens tested as evidenced by the small standard deviation lines bounding the average data. When the same procedure and target torque were applied to Taptite and ALtracs thread-forming fasteners, the resulting clamp load generated was ~ 5 Nm, or 50% of the value generated by machine screws at the same input torque. A series of tests was conducted with each fastener and each showed lower clamp load at the target torque, as shown in Figure 7, for Taptite fasteners. As with machine screws, the average data were very repeatable for the 10 fasteners and nut specimens tested, as evidenced by the small standard deviation lines bounding the average data.

After discussion with the Project Fastener Team, the target torque for all thread-forming fasteners was increased to a value beyond the assembly specification but which matches the clamp load generated by a similar machine screw under the same conditions. In the case of the Taptite fastener at 15-mm thread engagement shown in Figure 7, the new target torque was raised to 17 Nm and it generated ~ 9 Nm of clamp load upon initial testing and showed ~90% clamp-load retention throughout the 14 run-downs. Comparable results were observed for ALtracs fasteners when testing under similar conditions. The lessons learned during this test series will be adopted during future reusability testing for this project, to include 12- and 15-mm thread engagements in aluminum and magnesium nut specimens with a variety of thread-forming fasteners.

Approach to TFF Contamination Testing

Another issue to be investigated during this technical feasibility project is the extent to which contamination in the form of debris is generated while using thread-forming fasteners in die-cast, net-shaped holes. The approach to this test was to run a single fastener into the same hole and measure the metal fines generated as debris in the hole after disassembly of the joint. The debris was collected in a plastic dish and weighed on an electronic balance. In order to collect this debris, assembly of the fastener could not be done using the Labmaster test stand and constant-speed nutrunner assembly tool due to the space constraints of the load cell. Therefore, a hand-held drill was used to run the fastener into a nut specimen held in a bench-top vise. The assembly was performed horizontally with the plastic dish held under the joint during assembly and disassembly to collect any debris. The input torque capability of the hand-held drill was measured on a test piece using the Labmaster and was measured at 12 Nm. This sequence was repeated 9 more times for a single fastener for a total of 10 assembly/disassembly steps. Thread-forming M6 fasteners with the S437 coating supplied by Textron were used for this testing along with the

USCAR Fastener Committee
USAMP Die Cast Net-Shaped Hole Process Development

To: USAMP Die Cast Net-Shaped Hole Process Development Team

cc: USCAR Fastener Committee

Subject: **Die Cast Net-Shaped Hole Process Development - Fastener Service Recommendations**

Objective: Develop a baseline service metric by establishing a target torque with fastener trials, using worst case conditions.

Establish a baseline for screw performance using a machine screw and pre tapped hole:

Tighten 30 fasteners to failure using a torque-tension test method, and record clamp load, torque, & failure mode.

Establish a target torque from this data, based on 80% of the minimum failure.

Record clamp load at the target torque for a minimum of 15 rundowns (unless failure occurs sooner) reusing the same fastener and hole.

On the 15^{th} run, tighten the 30 joints to failure with the previously used torque-tension method.

Establish a target torque using a thread forming screw and non-tapped hole:

Set-up the estimated worst case conditions using a TapeTite 2000 SP thread form, a die cast hole taper with a 0.5° draft angle, a die cast hole at 90% of the screw diameter, and a length of thread engagement equal to 2.0 screw diameters.

Tighten 30 fasteners to failure using a torque-tension test method, and record clamp load, torque (drive and strip), & failure mode.

Determine the drive to strip ratio. It should be a minimum of 4:1.

Establish a target torque that will achieve the same mean clamp load as the machine screw did from the above test at the target torque.

Record clamp load at the target torque for a minimum of 15 rundowns (unless failure occurs sooner) reusing the same fastener and hole.

On the 15^{th} run, tighten the 30 joints to failure with the previously used torque-tension method.

Review the baseline data with the USCAR Fastener Committee.

Figure 5. Recommended test procedure for reusability of thread-forming fasteners into aluminum net-shaped, die-cast holes.

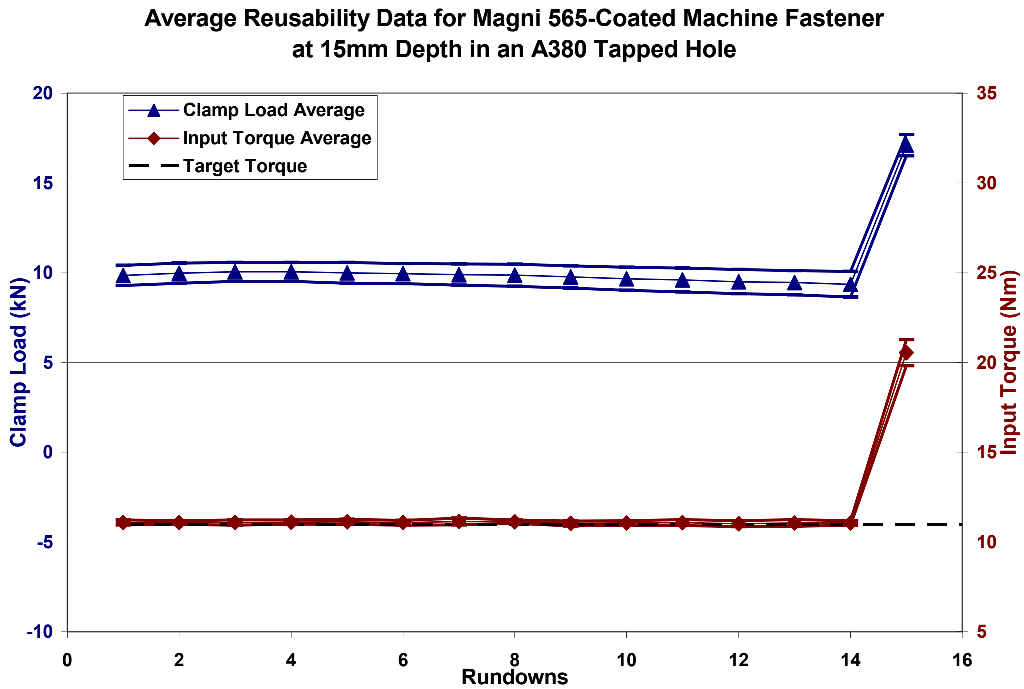

Figure 6. Clamp-load and input-torque data for consecutive rundowns of a single Magni 565-coated M6 machine screw into a drilled and tapped aluminum A380 die-cast nut specimen.

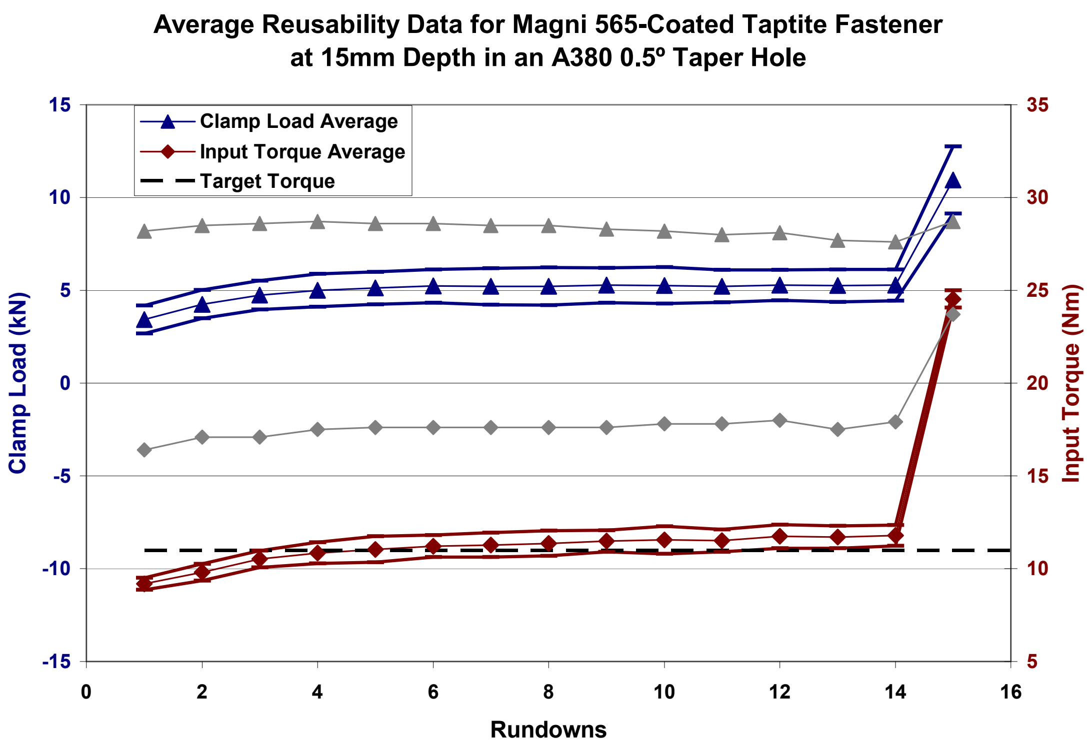

Figure 7. Clamp-load and input-torque data for consecutive rundowns of a single Magni 565-coated M6 Taptite thread-forming into a A380 die-cast nut specimen.

companion machine screws in drilled and tapped holes.

Results for TFF Contamination Testing

The initial contamination test of an S437-coated TFF into a 0.5-degree aluminum nut specimen generated a visible amount of metal fines in the dish which measured 0.035 grams. The next 9 run-downs generated 0.005 grams of additional debris for a total of 0.040 grams. It should be noted that the 0.005 grams is difficult to measure consistently and challenges the resolution of the electronic balance. For the next five tests using similar specimens and fasteners, the total debris collected during each series 10 run-downs of a single fastener into the same hole did not exceed 0.005 grams. The first run-down of the seventh TFF contamination test series performed similar to the first series and generated 0.035 grams of metallic fines, followed by 9 more rundowns that generated an additional 0.005 grams for a total of 0.040 grams. This dramatic variability in debris generation may be impacted by a variation in the horizontal alignment of the fastener/hand-held drill during the assembly process. A similar series of tests was performed using companion machine screws with drilled and tapped die-cast nut specimens. The debris generated during three series of tests with machine screws generated less than 0.005 grams of debris per test series. Again, it should be noted that this level of debris is difficult to measure consistently and challenges the resolution of the electronic balance. The contamination data for all of these tests are summarized in Table 1. For future testing, greater attention to detail will be applied to the alignment of the assembly tool to determine the impact on debris generation.

Approach to TFF In-Field Casting Variation Data

In-field data is being collected from various casting suppliers and analyzed to determine capability and to identify practices for achieving minimal variation in size, shape, and position of as-cast holes. Hole-position data will be measured daily on selected castings and forwarded to PNNL for analysis. Used core pins from the same die-casting dies will be collected and forwarded to PNNL for measurement to determine the rate of variation in size and shape of cast holes.

Laboratory tests have been conducted on the Lab Master Fastener Evaluation Test Cell at PNNL for various combinations of size (diameter) and shape (taper) holes to determine the range of variation that yields acceptable clamp loads. The in-field data and laboratory test-cell data will be compared to identify best practices and to determine gaps for further technical development. Several casting manufacturers are actively involved in the project, with varying stages of participation.

Five are fully engaged in collecting data:

- General Motors
- J R French
- Trace
- Metaldyne
- SPX Contech

Other casters participating in the project activities include:

- DaimlerChrysler
- Meridian
- Intermet
- Lunt

Conclusions

The impact of hole size and shape on clamp load was evaluated for Taptite thread-forming fasteners in aluminum alloy A380. Results from the hole size and shape evaluation indicate that at a taper of 0.5 degree, hole diameters at up to 0.05 mm above nominal (5.44 mm) would generate clamp loads and failure modes comparable to nominal conditions. Above this size, the risk of fastener stripping is high and detrimental to a useful joint. For hole sizes at nominal – 0.05 mm or below, the larger standard deviation is indicative of fastener galling. For holes with tapers at 1.0 and 1.5 degrees, the risk of fastener stripping was high in most cases. For the smaller 1.0-degree tapered holes where stripping did not occur, the standard deviation was large and again indicative of excessive galling.

Initial testing was completed in two areas of fastener serviceability as recommended by the USCAR fastener committee, specifically reusability and contamination. Lessons learned during this series of tests will be applied to future testing of

Table 1. Measurement of contamination in the form of metallic fine debris generated during assembly and disassembly of a single fastener into the same hole 10 consecutive times.

Test #	Fastener Type	Weigh of Debris of 10 rundowns
1	Thread-forming	0.040 grams w/ 0.035 grams on 1st rundown
2	Thread-forming	~0.005 grams
3	Thread-forming	~0.005 grams
4	Thread-forming	~0.005 grams
5	Thread-forming	~0.005 grams
6	Thread-forming	~0.005 grams
7	Thread-forming	0.040 grams w/ 0.035 grams on 1st rundown
8	Machine screw	< 0.005 grams
9	Machine screw	< 0.005 grams
10	Machine screw	< 0.005 grams

both aluminum and magnesium alloys with a variety of fasteners. For tests conducted with the modified procedure, results indicate that when using the same thread-forming fastener into the same hole, clamp load retention was in excess of 90%. Similarly, contamination tests were performed which indicated a minimal amount of debris is generated when thread-forming fasteners are used with as-cast aluminum nut specimens. Lessons learned during both types of testing will be applied to the next phase of work which has prototypical thread-engagement depths of 2 and 2.5 times the fastener diameter.

Future Work

The lessons learned during these initial serviceability tests on reusability and contamination assessment will be employed during future testing of aluminum and magnesium alloys to resolve the key issues identified for investigation during this technical feasibility (see Introduction for definition) project. In addition, in-field data will be collected from participating casting suppliers and analysis of hole size, shape, and position data will be conducted and compared to the clamp-load results generated using Taptite fasteners and aluminum alloy A380. Similar size and shape testing will be conducted on magnesium alloys as well using a variety of thread-forming fasteners.

Presentations/Publications

Abstract accepted by TMS for paper entitled "Application of Thread-Forming Fasteners in Net-Shaped Cast Holes in Lightweight Metal Alloys" to be presented in March 2006.

D. M. Paxton, "Application of Thread-forming Fasteners in Die Cast Net-Shaped Holes", USAMP Casting Off-Site Meeting, Detroit, MI, September 29, 2005.