FINAL Technical Report

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DOE Award Number:	DE-FC36-04GO14332
Project Title:	**Advanced Pattern Material for Investment Casting Applications**
Project Period:	9/30/2004 – 12/31/2005
Recipient Organization:	Cleveland Tool and Machine, 5240 Smith Rd., Brookpark, OH 44142
Partners:	buyCASTINGS, Harrington, S&A Consulting; All partners are cost-sharing.
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1. Executive Summary:

Cleveland Tool and Machine (CTM) of Cleveland, Ohio in conjunction with Harrington Product Development Center (HPDC) of Cincinnati, Ohio have developed an advanced, dimensionally accurate, temperature-stable, energy-efficient and cost-effective material and process to manufacture patterns for the investment casting industry.

The present method for investment casting is “The Lost Wax” process, which is exactly that, the use of wax as a pattern material, which is then melted out or ‘lost’ from the ceramic shell. The molten metal is then poured into the ceramic shell to produce a metal casting. This process goes back thousands of years and while there have been improvements in the wax and processing technology, the material is basically the same, wax. In the proposed technology, FOPAT (a FOam PATtern material) has been developed which is especially compatible with the investment casting process and offers the following advantages:

1. **Increased dimensional accuracy (viability shown in bench scale)**
2. **Increased temperature stability (viability shown in bench scale)**
3. **Lower cost per pattern (viability shown in bench scale)**
4. **Less energy consumption per pattern (viability shown in bench scale)**
5. **Decreased cost of pattern making equipment (will be shown in this program)**
6. **Decreased tooling cost (will be shown in this program)**
7. **Increased casting yield (dimensional and visual) (will be shown in this program)**

The proposed technology meets the EERE mission by enhancing energy efficiency, reducing energy use and increasing productivity. The technology also supports portfolio priority # 6 “Increase the Efficiency/Reduce the Energy Intensity of Industry.”

The proposed technology is based upon an established industrial process of “Reaction Injection Molding” (RIM) where two components react when mixed and then 'molded' to form a part. The proposed technology has been modified and improved with the needs of investment casting in mind. A proprietary mix of components has been formulated which react and expand to form a foam-like product. The result is an investment casting pattern with smooth surface finish and excellent dimensional predictability along with the other key benefits listed above.

The proposed program will develop and commercialize technology that will result in energy savings of 2,160 x 10^9 BTU’s per year in the investment casting industry (as a direct result of replacing the “The Lost Wax” method with the proposed FOPAT innovation). **This will save approximately $14M in energy costs per year as well an additional $195M in material savings**, making US Investment casters more competitive globally and will help save US manufacturing jobs. In addition, lead-time and scrap will be reduced, which will further enhance productivity and lead to more cost savings.

A team approach of CTM, the machine builder, Harrington Product Development Center, the material developer, S&A Consulting, the marketing strategist, and buyCASTINGS the industry commercialization outlet and program manager, will ensure that the proposed technology is commercialized and meets the goals of the I&I program.

The companies involved in the program are all small businesses and do not have the financial capability or the risk capacity to develop and commercialize the product without the aid of the I & I program.

2. **Project Objective:** To demonstrate the commercial feasibility of an advanced Foam Pattern or FOPAT material as a replacement for wax in the investment casting process.

3. **Progress Report and Project Accomplishments:**

Due to the lack of funding at DOE, the program was terminated in mid-course. We have continued to produce foam patterns for dimensional studies and also for casting trials. The foundries and potential customers that have evaluated the FOPAT patterns on trial basis are quite excited about the potential.

Key points and the task updates are shown below:

Had our last meeting in Dayton at buyCASTINGS on Nov.21-05 for I&I. Discussion about commercialization options was main topic of discussion.
Issued team mtg agenda, prepared slides, and gave a power point presentation on August 17, 2005 at CTM for future commercialization purposes. In attendance were a member of GE Engines, the Air Force representative, and all of the FOPAT team members Doug, Rick, Nip, Neil, and Bob to review the project technical progress, and to see a demonstration of the FOPAT injection trials at CTM in Cleveland. The consensus was that the FOPAT team has shown feasibility: pattern formulation done, pattern injections done, pattern measurements done

(more could be done), shell building done (in one foundry, more could be done), and investment castings made (two castings done, more could be done.) What remains to be done is: 1. MSDS/burn-off results to show there is no major concern with toxicity or VOC's during the casting phase; 2. Castings of a couple of different parts at couple of different foundries; and 3. Some additional dimensional measurements of the patterns vs the tools to show some additional data on potential accuracy and reproducibility.

buyCASTINGS and the team identified 6 foundries for casting trials using FOPAT patterns; An NDA was signed with all foundries. The first castings were done in July for a medical implant part cast at an Ohio foundry.

During the reporting period, several discussions took place with foundries as well as with GE. GE/AF SUPPLIER has interest in the material for their aircraft engine Outlet Guide Vanes (OGV's) but prior to shipping a large die to CTM in Cleveland, GE/AF SUPPLIER has shipped a smaller medical die (see photo 1 below) that will be injected with FOPAT and the resultant patterns (photo 2) sent to GE/AF SUPPLIER for casting and shell trials. The first pattern injected (shown below) had good dimensions, surface finish, surface feature details and the quality was deemed excellent by the GE/AF SUPPLIER engineer. We anticipate the pattern to also result in a good casting, in which case we will proceed with the dimensional analysis and detail studies of this medical part and the OGV die will need to be postponed to next year's activities.

Photo #1
GE/AF SUPPLIER Provided Pattern Injection Die

Photo #2
FOPAT Patterns Made in GE/AF SUPPLIER Die

Another foundry in Cleveland Ohio has also sent a small military die for trials. The die pictured in photo #3 below is important since it represents a small but thicker die that usually requires a chill prior to being placed in the die for proper wax injection before the final wax pattern is injected. This is done to minimize the "wax sink" that occurs when a heavy section of wax is cooling during solidification. We expect the FOPAT technology to be able to eliminate the sink and the chill, making the resulting operation more efficient – providing for a better first time yield for dimensions and a less costly and time consuming pattern injection. The patterns will be cast at the Ohio foundry location.

Injection Die from a Foundry

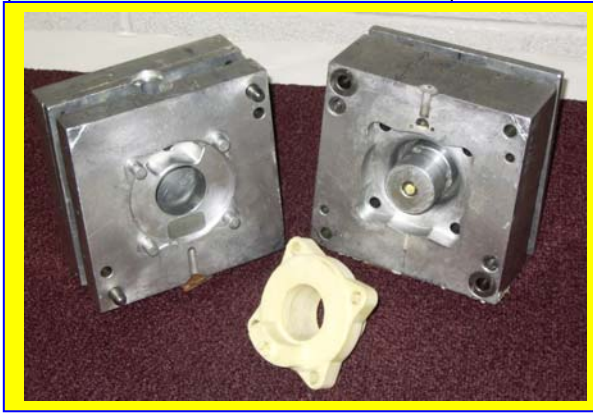
Injection die and FOPAT Pattern

In addition, a meeting was held with the Air Force, a Senior Designer at GEAE in Evendale to discuss the merits of the FOPAT process. They see a significant need in being able to cast thin sections. They were impressed enough with the thinnest area of the step block pattern to volunteer an older turbine strut faring die that had been used at a GE supplier to cast a thin section fairing.

Also a generic airfoil die has been constructed in epoxy from a prior wax pattern. This die is shown below and will be injected to show the versatility of the FOPAT process to easily inject long thin sections in less expensive epoxy dies vs machined aluminum dies used in the current wax process.

Epoxy Airfoil Die

The thinnest section of the airfoil is the 0.030" trailing edge and the main airfoil body only has a 0.100" thickness over a part that measures 8-9 inches in length.



Valve Die and FOPAT Pattern

Valve Die

Mold dimensional studies

A dimensional inspection will be done on all molds prior to injection of the FOPAT material. This information will be used to document the degree of shrinkage obtained in the resultant FOPAT patterns. Dimensional inspection will be done using laser scanning or other automated CMM techniques. buyCASTINGS will be responsible for this task.

The step block die was inspected and measurements documented. The results are shown in the charts that detail the pattern dimensions in Task below.

On 10-06-05 we did additional dimensional checks and rechecked all parts on 11-17 to see the effect of aging. Results were good.

A step block die was made from machining aluminum blocks to form a "step-die" which has seven different thickness sections or steps in one die as shown above. These seven steps allow the formation of a pattern which ranges in thickness from 1" down to 0.050" as shown below. Mold measurements were made on this die.

Preliminary results of the step block die measurements are highlighted below:

Die	Dimension 1	Dimension 2	Dimension 3	Dimension 4	Dimension 5
Step Block Die	**0.200/0.201**	**0.066/0.067**	**1.016/1.018**	**1.014/1.015**	**4.060/4.064**
Step Block Pattern #1-Tan	0.198/0.196	-----	1.025/1.028	1.028/1.30	4.035/4.040
Step Block Pattern # 2-Tan		0.68/0.69	1.025/1.026	1.025/1.026	4.103/4.105
Step Block Pattern # 3-Green	0.202/0.203	0.065/0.66	1.025/1025	1.026/1.028	4.104/4.106
Step Block Pattern # 4-Blue	0.200/.0.201	0.070/.068	1.025/1.027	1.023/1.025	4.105/4.107

Step Block Dimensional Inspection

Note: we also measured the same patterns one week later and found that there was no appreciable dimensional change.

Inject trial patterns

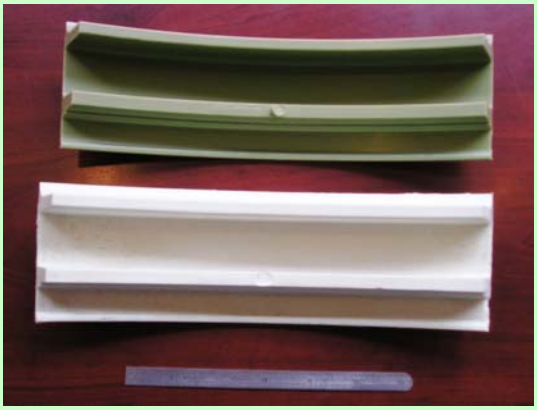
The FOPAT injection trials have been running at CTM on the demo injection machine to determine the acceptability of the FOPAT material for consistency of injection, surface finish and cycle time. The sample molds have been used for the trials.

Preliminary injection trials were held at CTM, the first trials were to determine the appropriate material to be used for the patterns. After those trials were complete in early July, pattern injection trials were started in earnest for the step block die, hip die, the airfoil die and the Ohio Foundry military die. Capability to inject color into the patterns was also demonstrated in one of the step block patterns as shown here.

Additional pattern trials were made on several of the available molds to further quantify some of the important injection parameters.

Step Block Die and a Green Color FOPAT

None of the dies injected were specifically made for the FOPAT injection and this plays a significant part in the quality of the resultant patterns. There are several important aspects that need to be addressed in any die that is being designed for a given process. Process parameters of the parts need to be optimized in order to design dies correctly for this process and will require additional funding and needs to be addressed. Several of the patterns that were injected were sent to GE/AF SUPPLIER as well as Ohio foundries for casting.



Patterns of Shroud Liner Made from FOPAT (white) and Wax (green)

One significant aerospace pattern that was made is a shroud liner. **The FOPAT pattern is shown here along with a wax pattern that was injected from the same die**. The pattern were taken to GEAE on September 29th, 2005 and shown to a gathering of designers and casting engineers for their review and comment. Favorable comments were received regarding the surface smoothness, pattern stiffness as well as density of the FOPAT pattern. Consensus among all attendees was that the process has significant advantages.

One problem that was addressed was the cycle time. Previously the de-mold time was too long and therefore ***Not Competitive.*** We made several adjustments to bring down the de-mold time. This puts us in the range we need to be in. Further work will be done to further improve cycle time. Further studies concluded that the adjustments we made helped cycle time without affecting the dimensions.

Commercialization

During the past 3 months, buyCASTINGS has identified 6 different parts for potential production using FOPAT patterns. If commercialized successfully, these parts could have an annual volume of over 1.3 million pieces. Some additional points on commercialization task:

- A continued effort is being put forth to find additional interest and funding for future commercialization of the FOPAT technology – Currently working with GE, GE/AF SUPPLIER, and the Air Force.
- Team meetings were held 3 times this quarter 2 at CTM and 1 at bC in Dayton.

A preliminary write up on commercialization plan was also done.

- Meeting minutes, action items and agenda was compiled and distributed for each of the team meetings in the quarter 3 reporting period.
- As part of the Continuation Application submitted to I&I in September 2005, CTM submitted a letter stating our position on the patent issue and future commercialization. The letter summarized the facts: That the search had revealed that Howmet Corporation had filed a patent. We were also told that the patent could be nullified due to the reason that Harrington who is one of the partners in our project had already sold and received purchase orders for similar foam patterns greater than one year prior to the Howmet filing. That our legal council has advised that we should proceed and if challenged we would simply advise that the on-sale bar applies. We can however have our composition of material consider as a proprietary mix by our supplier and thus need not be shared with others.
- Cleveland Tool specified some enhancement features to the base RIM machine which has been used as the FOPAT demo machine for injection trials. The modifications would require additional funding which we are seeking from the AF and would enable us to handle larger parts with better parameter controls.
- Cleveland Tool conducted several FOPAT Injecting trials working with bC to obtain tooling and with material supplier to obtain proper composition, mixing ratios, and feed weights in addition to heating tools and doing dimensional inspection.
- After trial and error on several mixes we have found a suitable material and injected several different molds. A medical implant, commercial valve, and a step block mold.
- Tested 6 different mold releases and found a suitable release agent that works well.
- An Ohio Foundry, one of the companies that agreed to do a casting trial shared the casting results on medical implant part, shown in the results section, along with the dimensional measurements to show excellent accuracy and consistency in pattern dimensions vs tooling dimensions ie no shrinkage experienced as commonly seen in wax patterns.

4. **Patents:** No patents were filed.

5. **Publications / Presentations:** An abstract was presented to the Investment Casting Institute and they have approved of FOPAT giving a lecture at their annual ICI conference in Dearborn Michigan in November. Two of the FOPAT partners, Harrington and buyCASTINGS were to present, however, the team decided to postpone the paper and the presentation since the commercialization is expected to be not until spring of 2006 at the earliest ie we are not yet prepared to hand out samples or produce any samples for potential customers. (Basic process parameters need to be optimized and production readiness/scale up work must be done first.)

6. **Budget and Schedule Status**: Budget and schedule is attached in the requested tabular format.

7. **Plans for Next Quarter:** **No Plans –** Project for I&I stopped due to discontinuation of funding

All final reports should be publicly disclosable and not contain confidential, proprietary or business sensitive information. Any relevant confidential, proprietary or business sensitive information should be forwarded under separate cover to the Project Officer.

Task Schedule

Task Number	Task Description	Task Completion Date				Progress Notes
		Original Planned	Revised Planned	Actual	Percent Complete	
1	**Admin, Reporting & Project Management**					
1.1	Team Joint Venture	12-31-04		3-31-05	100%	LLC/partnership formalized to commercialize product
1.2	Patent application processing	3-31-04	6-30-05	6-10-05	100%	Search revealed existing patent
1.3	Patent application submitted	9-30-05		6-10-05	0%	Cannot patent But can continue work
1.4	6 Month Technical & Commercial Progress report	3/31/05	4-30-05	4-29-05	100%	Submitted
1.5	1 year Technical & Commercial Progress report	9/30/05		8-19-05	100%	Completed - Continuation Application Submitted
1.6	Program Administration and technical management			DONE	100%	Reports as required, team meetings, tech coordination
2.0	**Machine Build**					
2.1	Demo Machine Design	12-31-04	9-15-05	9-15-05	100%	Purchased base machine and modifications completed
2.3	Demo Machine Build	6-30-05	9-15-05		95%	Currently have a functioning RIM machine and adding clamping unit
2.4	Demo machine trials	9-30-05	5-30-05	6-01-05	100%	Injected several different molds
3.0	**Pattern Material**					
3.1	Pattern material composition trials	3-31-05	4-21-05	6-15-05	100%	Currently have a workable pattern material
3.2	Pattern Material primary injection trials	6-30-05		6-15-05	100%	Ran several molds on RIM machine
3.3	Pattern material report	6-30-05	7-29-05		75%	Awaiting manufacturers analysis

Task Schedule

Task Number	Task Description	Task Completion Date				Progress Notes
		Original Planned	Revised Planned	Actual	Percent Complete	
4.0	**Industry Participation**					
4.1	Develop Industrial Survey	3-31-05	4-30-05	5-05-05	100%	Draft survey done
4.2	Conduct Industry Survey	9-30-05	11-30-05		90%	Initial surveys sent. May need to adjust survey
4.3	Industrial survey conclusions	9-30-05	12-31-05		60%	Preliminary Conclusions In
4.4	Choose foundries for trials (6 min)	3-31-05	5-15-05		100%	6 foundries chosen for casting trials
4.5	Commercialization plan	9-30-05			70%	Strategies: sell FOPAT patterns, License technology; No assistance available from DOE resource
5.0	**Pattern& Casting Trials**					
5.1	Obtain/Modify molds for patterns	9-30-05		9-30-05	100%	Multiple molds chosen and injected
5.2	Inject trial patterns	9-30-05			85%	Multiple molds injected successfully, optimization in process
5.3	Industry Trials (dimensional, pattern, casting)	3-31-06			30%	Have one pattern out for trial. Will send several more out during next few months
5.4	Mold Dimensional study	9-30-05		9-30-05	100%	Step block die dimensions complete
5.5	Pattern dimensional study	12-31-05			70%	Preliminary results show minimal expansion and no shrinkage
5.6	Casting dimensional study	3-31-06				Not started
5.7	Dimensional study report	6-30-06				Not started

Task Schedule

Task Number	Task Description	Task Completion Date				Progress Notes
		Original Planned	Revised Planned	Actual	Percent Complete	
6.0	**Technology Transfer (trade shows, newsletters, communications)**					
6.1	American Foundry Society trade show	6-30-05		6-30-05	100%	Booth and display rented – Had team meeting at location
6.2	Investment Casting Trade show	9-30-05	11-15-05		100%	Will Have Booth at ICI in November-
6.3	Present papers at ICI and AFS Conferences	9-30-06			40%	ICI paper done but not submitted; AFS Paper drafted
6.4	Newsletters sent to industry	9-30-06			20%	Placed 2 ads in newsletters
6.5	Targeted Email campaign	9-30-06				Not started
7.0	**Commercialization**					
7.1	Sale of first patterns	9-30-06				Not started
7.2	Final report	9-30-06		2-07-06	100%	Funds cut –I&I program done

Spending Schedule

Task	Approved Budget	Project Expenditures Cumulative to Date
Task 1 **Admin, Reporting & Project Management**	29,000	92,327.31
Task 2 **Machine Build**	85,000	73,377.51
Task 3 **Pattern Material**	23,000	18653.50
Task 4 **Industry Participation**	29,000	23,974.42
Task 5 **Pattern& Casting Trials**	44,000	51476.63
Task 6 **Technology Transfer**	27,000	9,723.20
Task 7 **Commercialization**	3,000	21,981.31
Total	250,000	291,513.88
DOE Share	250,000	156,096.00
Cost Share	170,600	135,457.90

Cost Share Contributions

Funding Source	Approved Cost Share (for the 2-yr project)		Cumulative to Date (Through the First Project Year)	
	Cash	In-Kind	Cash	In-Kind
Cleveland Tool and Machine	60,000		40541.66	
buyCASTINGS	54,000		55737.57	
Harrington Product development Center	24,000		22,878.00	
S&A Consulting	33,000		16,300.00	
Total	171,000		135,457.90	

FOPAT Project
(Award number: DE-FG36-04GO14332)

Project Spending and Estimate of Future Spending

Calendar Year Quarter	From	To	Estimated Federal Share of Outlays*	Actual Federal Share of Outlays	Estimated Recipient Share of Outlays*	Actual Recipient Share of Outlays	Cumulative Actual Outlays (Federal + Recipient)
	Start	9/30/04	Note 1	Note 3	Note 1	Note 3	Note 3
4Q04	10/1/04	12/31/04	20,000	12,584.63	18,075	44,504.81	57,089.44
1Q05	1/1/05	3/31/05	61,500	23,372.31	22,075	21,915.99	45,288.30
2Q05	4/1/05	6/30/05	71,000	86,186.67	20,075	25,128.75	111,315.40
3Q05	7/31/05	9/30/05	33,500	31,222.00	22,075	31,724.92	62,946.92
4Q05	10/1/05	12/31/05	18,000	2,690..39	22,075	12,183.41	14,873.80
1Q06	1/1/06	3/31/06	13,000		22,075		
2Q06	4/1/06	6/30/06	18,500		22,075		
3Q06	7/1/06	9/30/06	14,500		22,075		
Totals			**250,000**	**156,096.00**	**170,600**	**135,457.88**	**291,513.88**

* Update quarterly

General Note: The information in this table should be consistent with the information provided in section 10 of the quarterly financial status reports (SF269 or SF269A).
Note 1: Leave blank. Only the actual DOE/Cost Share amounts spent through the latest completed quarter are needed.
Note 2: Amount for this quarter and subsequent quarters should be updated as necessary on a quarterly basis. Estimates need to be provided for the entire project. If spending for a given quarter is different than estimated, then the remaining quarter's estimates should be updated to account for the difference. Total DOE and Cost Share amounts should be the same as the Award amount.
Note 3: This amount is the same as submitted last quarter on the quarterly financial status reports (SF269 or SF269A).