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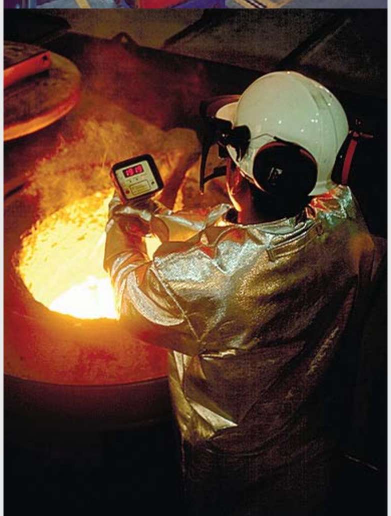

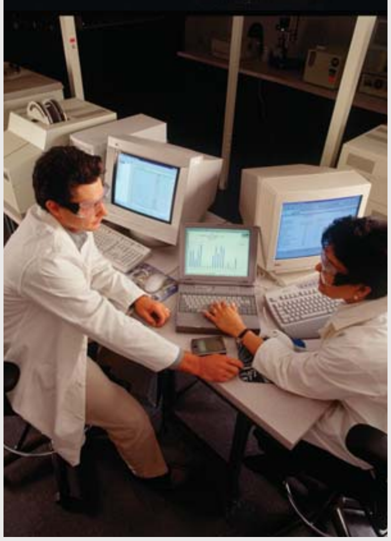

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Digital Mold Printing: Demonstration and Evaluation

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Digital Mold Printing: Demonstration and Evaluation

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This report has been reviewed for completeness and accuracy and approved for release by the following:

Director of Advanced Technologies	*//Original Signed//* Leo Dobitz	Date
Vice President	*//Original Signed//* George Crandell	Date

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EXECUTIVE SUMMARY

The intent of the digital mold printing demonstration effort was two fold. First was the desire to evaluate the process against conventional Army foundry processes performed at Rock Island Arsenal (RIA) and second, to determine under what circumstances this technology would be both applicable and economical for Army applications.

By definition, digital mold package printing allows the production of a complete sand mold/core package directly from a Computer Aided Design (CAD) model of the desired cast part. In simplistic terms, this is done by binding thin layers of part geometry in sand and building layer upon layer resulting in a three dimensional sand mold. Those precursory efforts normally required in developing a tooling/pattern package (i.e. rigging design, gating/risering, shrink, etc.) are incorporated into the CAD model for printing. Since this is all accomplished in a digital environment, manipulation and changes are accomplished with little effort and no requirement to modify hard tooling. The process eliminates the need for patterns and core boxes and the lead time and cost associated with their manufacture.

The digital printing equipment selected for this effort was an S-15 Rapid Cast Technology (RCT) by Pro Metal, a division of The Ex One Company. It was selected because of its materials compatibility with the existing RIA molding system (furan based sand system). Also, the S-15 system is capable of printing molds for both ferrous and non-ferrous metals, a requirement for RIA workload.

Both a ferrous and non-ferrous part was selected for the effort. CAD solid models of the parts were supplied to the vendor for the addition of rigging and the eventual building of the mold model. This model was converted to an STL file from which the S-15 created the sliced file to print. Since the printing takes place in a sand bed, support super structure, common in most rapid prototyping equipment, is not required. This results in only printing that which represents the final mold package.

The demonstration process steps for both parts were the same (i.e. CAD model, add rigging, solidification simulation and print mold). After this effort, the molds were printed in

Irwin, PA and shipped to RIA for assembly and pouring. Two of each part were poured at RIA and underwent the normal post processing required by the technical data package. In both cases, serviceable parts were produced.

The RCT process proved to be a viable competitor in cast part production, especially in lead time and complex part geometry. The elimination of hard tooling to produce a first article or prototype part makes the process very competitive for small lot runs and multiple prototype iterations. The more complex the part geometry (i.e. lacycores), the more competitive the process becomes. The digital versatility also allows the production of different configurations concurrently. This is extremely efficient for small lot production of assemblies that require several different cast parts.

The economical break even point for the technology is a moving target. The more complex the part, the higher the production number break even becomes. In single part production, without existing tooling or prototypes, conventional processes are not competitive. In the case of lead time, the process produced molds well ahead of the conventional methods. Obviously, complexity and quantity are big drivers in the economical feasibility of the process. Based on the demonstration efforts, the technology has a niche that makes it the most economical and effective process in production requirements that require rapid turn time and are of smaller quantities. System development and prototypes also fit into this niche.

Hybrid mold packages (i.e. printed cores and conventional mold) were not developed during this demonstration effort but have even greater potential for being economical and competitive. Complex core packages can be printed in a single unit thereby eliminating multiple core boxes, core assembly and core registration problems. Not printing the bulky mold frees the S-15 to produce the complex portions of the mold package in greater numbers and integrate them into the conventional molding process. This would drive the break even quantity higher.

The S-15 RCT would significantly complement the current Army casting process since it is driven by short lead times, low quantities and complex geometry with stringent quality requirements. Multiple iterations of tooling design could be proven out to produce first articles prior to investing in the cost and lead time associated with hard tooling. This would allow the optimization of a process before going into a production run of significant quantities. RCT is a technology that should be seriously considered in future modernization/capability enhancement efforts within the Army organic maintenance structure in support of field activities to both reduce lead time and costs.

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1.0 ABSTRACT

Metal castings are ubiquitous in consumer and military products and are increasingly being evaluated for cost implications in new product development programs. Conventional casting production normally requires using a "pattern" technique, which is the critical and integral initial production step of the casting process. Once component design is complete, the "pattern" is typically the longest-lead item, represents considerable expense, is produced from a diminishing pool of skilled trade resources and imposes a lack of agility to new product development programs and compressed lead-time requirements for legacy components. Three-dimensional printing technology continues to develop new materials, processes and equipment for emerging markets, novel applications and as a means to decrease costs and timing compared to conventional manufacturing techniques.

Many processes currently on the market (Stereo Lithography Apparatus, Stratus, etc.) allow the digital printing of a pattern that integrates into the conventional casting process via investment molds or loose patterns to produce tooling. Several manufacturers are now marketing digital printing equipment that allows the production of a sand mold package directly from a 3D CAD file, bypassing the normal intermediate pattern step. The commercial development of this technology builds upon research and patents accomplished at Massachusetts Institute of Technology (MIT). The beauty of the process is its digital nature which permits rapid design changes without the associated cost of tooling manufacture or modification. There also appears to be some level of production, depending on part geometry, that would be cost effective using this process as opposed to the cost and lead-time involved in conventional tooling. The digital environment also allows a large degree of latitude in design since many of the traditional casting rules can be violated without adverse consequences (elimination of draft, cores integral to mold, etc.).

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2.0 PURPOSE

The purpose of the Rock Island Arsenal Joint Manufacturing Technology Center (JMTC) Digital Mold/Core Printing demonstration project was to evaluate the capability, compatibility and effectiveness of the digital mold printing process. It is being evaluated against conventional molding techniques applied to typical DOD workload at RIA's JMTC for consideration as a potential technology insertion effort. Typical production requirements for the Army at RIA include small production lot sizes, complex geometry with stringent quality requirements, various alloys, legacy components and desired short lead times to support critical mission requirements.

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3.0 PROCESS DEFINITION / SELECTION

For this demonstration effort, the digital mold printing process was defined as the ability to produce sand molds and cores for casting various metals (i.e., both ferrous and nonferrous), using conventional foundry materials, directly from a 3D CAD file, bypassing the tooling/pattern requirement.

Four different vendors' products were initially investigated for participation in the demonstration effort. Based upon system compatibility with RIA current process capabilities, only one commercially available product appeared to be able to meet the requirements. A second product appeared compatible for the effort but required chemical leaching of the core materials, a process not consistent with current capabilities at RIA. Adding the capability to leach core material from a casting is not considered an insurmountable obstacle to the demonstration effort. Unfortunately, the system is not commercially available without extensive redesign and associated long production lead-time (four years). Therefore, it was not included in the evaluation. Two other systems commercially available were not compatible with the elevated temperatures used in pouring steel. They would be sufficient for less heat intensive pours such as aluminum and advertised equal performance characteristics. Because of the inability to handle steel pours, which represents the bulk of the RIA foundry workload, these two systems were not included in the evaluation effort.

Of the vendors contacted for possible participation in the demonstration project, only the Rapid Casting Technology (RCT) system from The Ex One Company was compatible with the current conventional casting process requirements at RIA. It incorporates like materials, emulates conventional casting practices as far as material handling is concerned, can withstand the pouring temperatures of the various alloys used at RIA, and is readily available in the commercial sector with a complete technical support package.

The RCT is a systems approach to manufacture sand molds and cores without the requirement to manufacture patterns or core boxes. Using the technical principles embedded in 3D Printing technology, complicated sand molds and cores are 3D Printed in the 1.5M x 0.75M x 0.70M Job Box, using conventional foundry sand, resin binder and an activator (see Appendix B for Material Safety Data Sheets for materials used). An integrated material handling system transports the Job Box from the 3D Printing Process Station, by means of powered material conveyance equipment, to the Unloading Station, where the molds and cores are removed. Simplicity in the system design enables alternative layouts and the ability to reconfigure the equipment as production requirements change. Since the RCT process does not require a pattern to produce the casting, small job lot quantities that do not have available tooling, low volume product development applications and low volume niche production are ideal candidates when response time, set-up charges for small batch production and tooling costs must be minimized.

The RIA process, against which the comparisons were made, utilizes conventional foundry equipment which has been in place at RIA for over twenty years. The Ex One Company equipment was used in the digital mold printing evaluation process. For this effort, the molds were actually printed in Irwin, PA and Keyport, WA then packaged for shipment to both RIA and Technikon.

Shown below (Figure 3-1) is the RCT S-15 Process station and Unloading Station. The Process Station uses a print head to dose the binder onto each layer of silica sand, where the mold geometry is required. Repeating the layering process produces the three-dimensional geometry.

Figure 3-1 S-15 Process Station

Figure 3-2 shows the Job Box entering the Unloading Station via a powered roller conveyor. Molds and cores are extracted from the Job Box as the bottom plate is raised, exposing the parts for final cleaning.

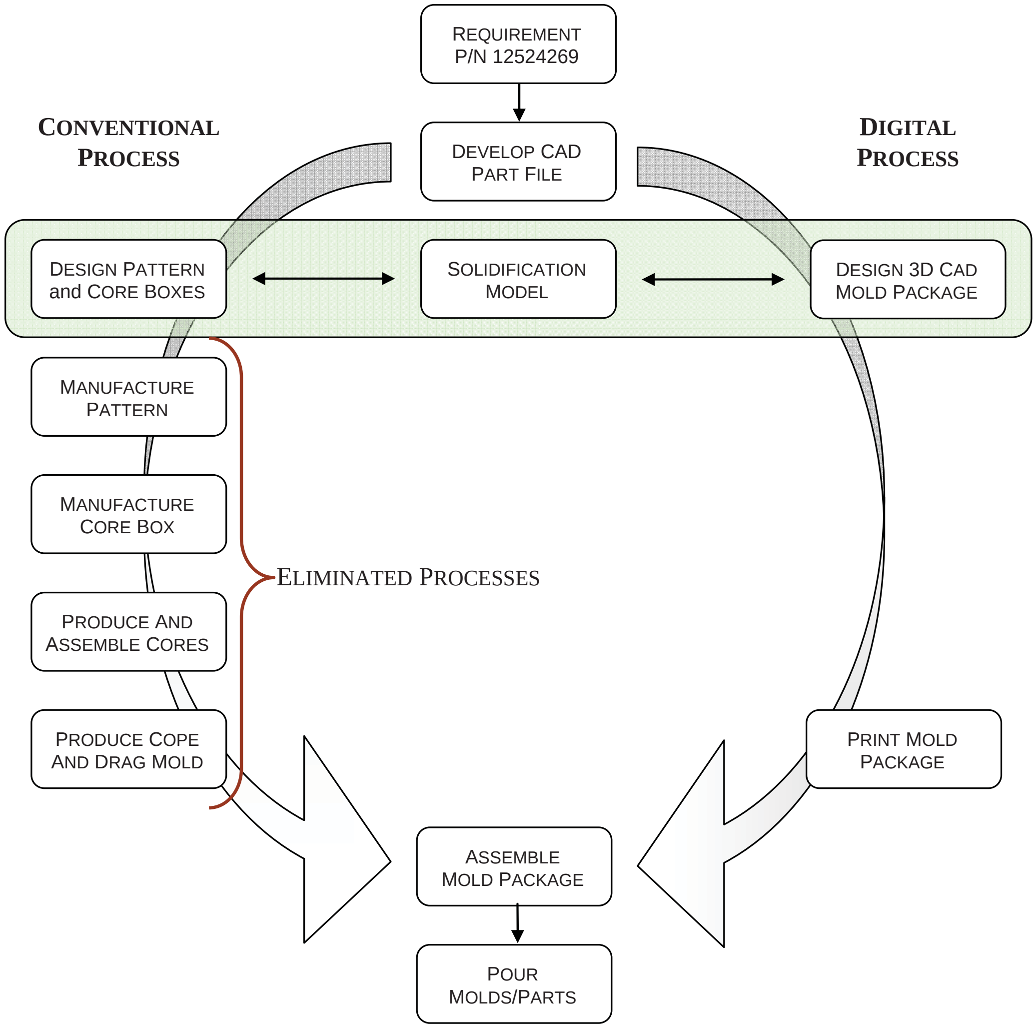
Figure 3-2 Job Box Entering Unloading Station

Figure 3-3 is a photo of the first demonstration part mold packages during extraction from the build box. Four complete three-part mold packages were printed in a single build box.

Figure 3-3 Mold Extraction

Figure 3-4 provides a graphical representation of a comparison to help demonstrate the process differences between the conventional RIA process and RCT processes.

Figure 3-4 Process Comparison Chart



The left side represents the conventional sand casting process where patterns and core boxes are manufactured to produce molds and cores. The right side represents the digital process that eliminates the need for hard tooling. The center section represents those operations that are required by either process.

The shaded green rectangle represents the solidification modeling process. This is not a required process in developing the mold configuration but it increases the likelihood of producing a serviceable part the first time by either process. It becomes more important as design geometry requirements create more complex geometry with thinner sections and more stringent porosity and metallurgical specifications.

The inherent flexibility becomes obvious when a change in the tooling is required. In the digital arena, only the CAD model requires modification whereas in the conventional process, all the affected tooling would require modification.

The conventional sand casting process requires a pattern or series of patterns to produce sand molds. All the sand molds will be a negative of the pattern and will be identical, thereby producing the identical cast part.

In the digital process no pattern is built to produce the molds. Because the molds are produced (3D Printed) directly from the CAD file, each and every mold can be unique which provides the opportunity to produce unique castings. This allows nearly unbounded flexibility in mold geometry being printed concurrently. This has huge schedule implications when producing small lot sizes of various parts.

Figure 3-5 shows various sand molds and cores printed in the Job Box during one production build. This demonstrates the flexibility of simultaneously producing unique multiple, patternless sand molds and cores directly from CAD files.

Figure 3-5 Build Box Loading

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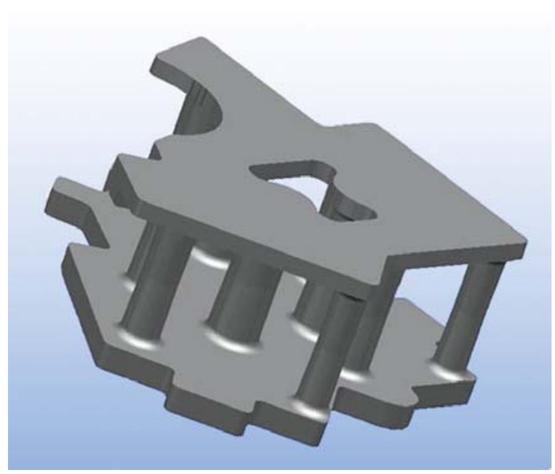
4.0 DIGITALLY PRINTED MOLD DEMO NUMBER ONE

4.1. Model Simulation

After careful consideration of several parts, the Feeder, Forward P/N 12524269, Figure 4-1, was selected for the first demonstration effort. Based on RIA history in producing the part, it provides a unique set of challenges in spite of its apparent simple geometry. Because of the part design, solidification needs to be controlled to minimize porosity and hot tears to produce a serviceable casting. In addition, the part requires radiographic inspection to verify very stringent technical specifications. The feeder has been problematic during production and has resulted in several iterations of chills to achieve the desired results. Since this is a current production part at RIA and applicable process data already exist, it presented an opportunity to compare the new technology against established methods.

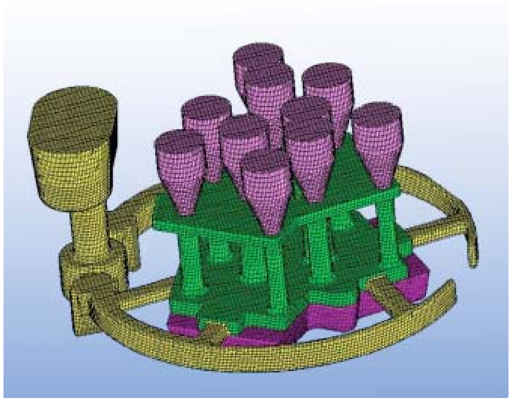
Figure 4-1 Feeder, Forward P/N 12524269



Along with the complete technical data package, a native Computer Aided Design (CAD) part file was supplied to the vendor. RIA also supplied an “as cast” part with rigging showing how the part is currently being produced. This was done for information purposes only and not as a process requirement. The vendor was not constrained by the current RIA process and was not required to replicate it in order to allow them the flexibility to demonstrate the full range of the capability of their technology. Since the digital mold printing technology allows much greater freedom in developing the mold package by violating traditional molding rules (i.e. no draft etc.), the vendor had the flexibility of designing their own rigging that best supports their technology.

The Ex One Company, via subcontractors Advanced Tooling Design (ATD) and EKK, generated a finite element model (FEM) from the STL surface files using the CAPCAST automatic 3D FEM mesh generator commercially available from EKK. The mesh model shows the chill under the part depicted in green in Figure 4-2.

Figure 4-2 Mesh Model with Chill



The demonstration was to be a complete process effort. Therefore, it included solidification modeling in an effort to increase the probability of producing a serviceable part on the first pour. The attached Power Point presentation, Appendix C, contains more pictorial detail on the mold design/build used in the solidification modeling effort.

4.2. Simulation Effort

The initial sand casting simulation was performed using the parameters shown in Table 4-1.

Table 4-1 Sand Casting Simulation Parameters

Initial Temperatures	
Al 356.2	704° C
Sand Mold	25°C

Latent Heat of fusion for Al 356.2	
Initial Viscosity	0.015 poise
Latent Heat	95.7 cal/g
Liquidus Temperature	622.0°C
Solidus Temperature	555.0°C

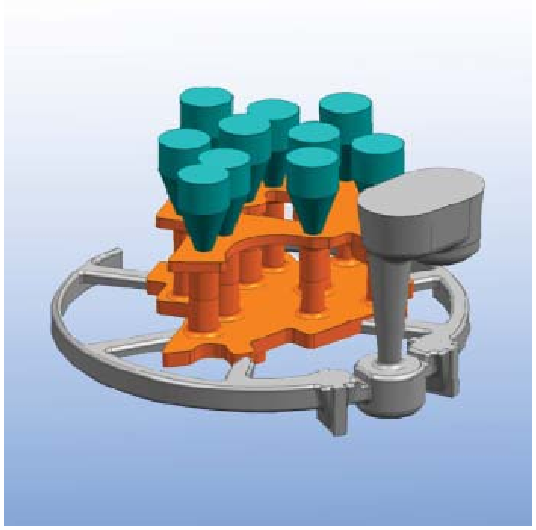
Heat Transfer Coefficients	
Casting vs. Sand	0.2 cal/cm^2 sec. °C

Filling Parameters	
Desired Fill Time	9 sec.

Material Properties	Density g/cc	Specific Heat Cal/g.K	Conductivity Cal/cm sec. °C
Al 356.2	2.1646	0.285	0.3988
Sand	1.8	0.217	0.0015

4.3. Filling Analysis

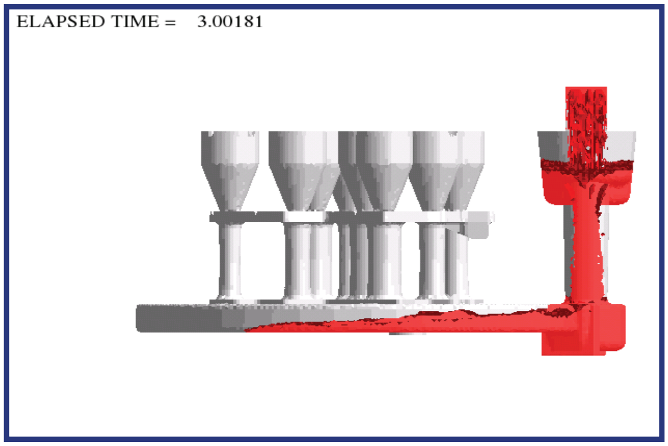
Figure 4-3 Casting, Gating & Runner Assembly



Filling analysis number one was performed without a filter. Comments on analysis number one as provided by the vendor:

> "The actual filling of the casting cavity is unremarkable. The fluid enters through the gates with a velocity of not much more than 25cm/sec. There are no pauses anywhere during the casting fill that might cause misrun defects. There is quite a bit of turbulence at the bottom of the sprue. The fluid falls from a relatively great height for almost the duration of filling. This is unnecessary turbulence (Figure 4-4) that may lead to oxide caused defects in the casting. At a minimum, reducing the cross/sectional area of the sprue must be considered in order to give the fluid somewhat of a cushion as it reaches the bottom of the sprue. There would seem to be quite a bit of room to increase the rate of fill of this casting. Fluid is entering the casting at a relatively low rate. It could be sped up by about 20 cm/sec at each gate without much worry of turbulence problems. A faster fill would also mean that the likelihood of misruns caused by the chill plate would be reduced as well."

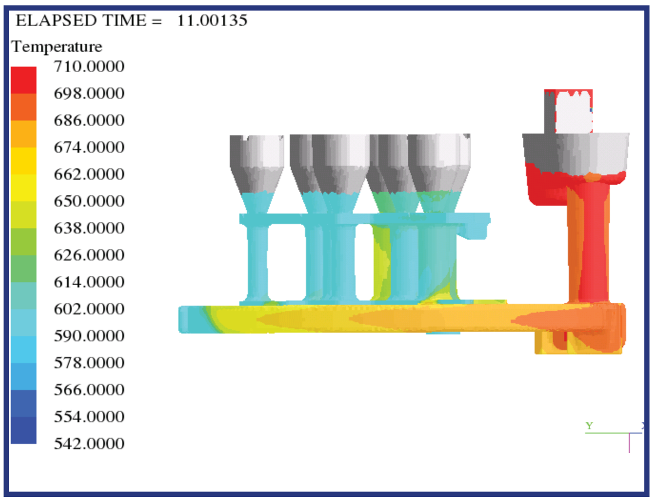
Figure 4-4 Fill Simulation



Examining the fluid temperatures during the fill leads to the conclusion that either the filling must be faster, or the iron chill is too large. Near the end of the fill there are significant regions of the cavity on the upper surface that have cooled to a point where solidification is already taking place. The fluid is so cool on the top surface because this is the fluid that encountered the chill at room temperature. Filling the cavity faster would prevent some of this excessive heat loss. Reducing the chill size must also be explored as an option as well.

Figure 4-5 is a visual representation of the temperature gradient as the part filled. As evidenced by the color change during filling, the metal is solidifying before it enters the risers. This reaffirms the need to fill the part in significantly less time or reduce the size of the chill. This observation led to modifying one of the two chills made for the demonstration pour. After discussion with all involved, some rigging was changed and filters were added to the gating system. A second filling simulation was then run.

Figure 4-5 Filling at 15 Seconds

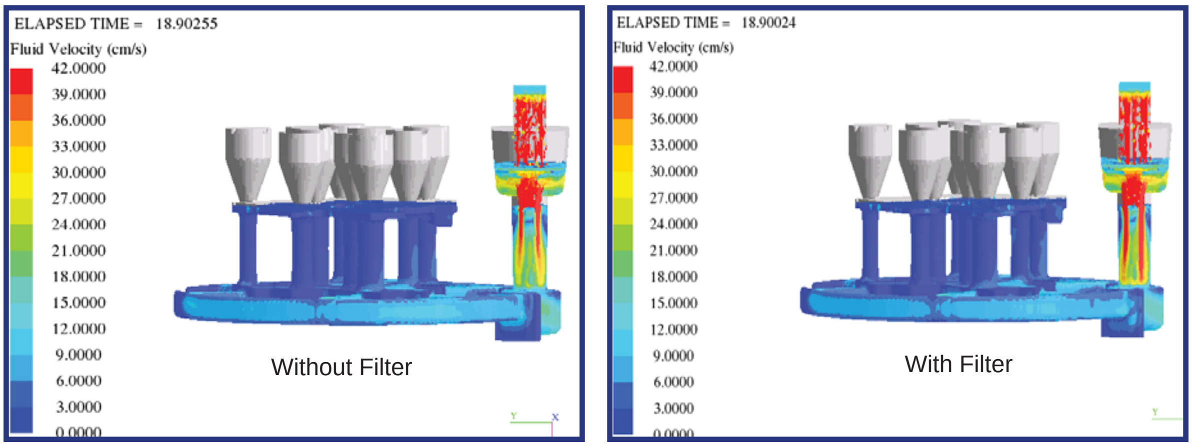


Filling analysis number two was performed with a filter. Comments on analysis number two as provided by the vendor:

> "The simulation included filters at both sides of the sprue. It was hoped that the filters would slow the fluid leaving the sprue enough so that the sprue tower might fill up and give a cushion to the falling fluid in the sprue itself. The filter does not seem to be successful in this mission. There is only a very slight change in overall speed and the sprue never really fills up enough to create a sufficient cushion."

Figure 4-6 is a graphic representation of the filling rates both with and without the filters. As one can see by the elapsed time on each view, there is little to no difference in the rate of filling. The filters were completely ineffective in slowing the fluid and the sprue showed no evidence of providing a choke. The process review, with all involved parties, resulted in a concern with the filling rate. Collectively, the decision was made to attempt to get the pour time to less than ten seconds. This resulted in a third filling simulation.

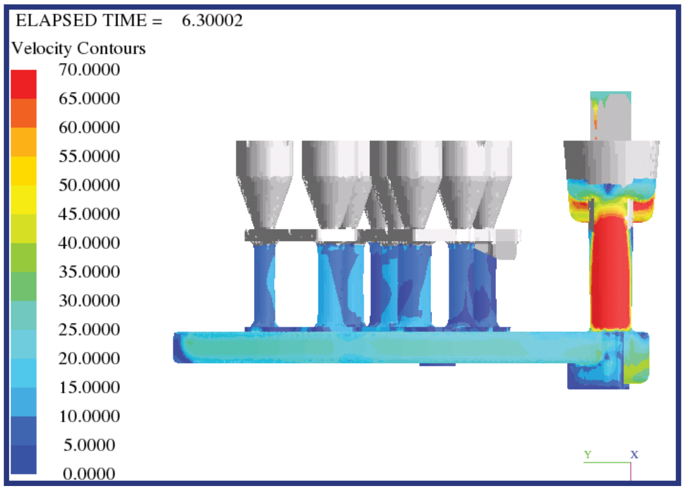
Figure 4-6 With and Without Filter Fluid Velocity Comparison



Filling analysis number three was performed using an increased filling rate. Following are the vendors' comments on the results of analysis number three.

> "The filling velocity is set at 3X original rate and fills the cavity in about 11 seconds. The pouring cup does overflow a little towards the end of the simulation. At about 9.9 seconds the fluid reaches the very top of the filling cup. In real life this would indicate that there would be some molten alloy spilling over at that time. Reducing the pouring amount at about 9.5 seconds or sooner would prevent any overflow and would likely not affect the filling of the cavity. That the pouring cup does not fill up until very late in the simulation indicates that it is quite possible to fill the cavity even faster, though a constant fill rate would not be possible.

Figure 4-7 Three Times Fill Rate



As evident in Figure 4-7, the part fills in about seven seconds as opposed to the original 20 seconds. This rate also supported a higher temperature gradient which eliminated the concern for misruns.

4.4. Solidification Analysis

Solidification analysis was performed with and without a chill. Following are the vendor comments on the results of the "with chill" analysis.

> "The chill plate at the bottom of the cavity is very effective at creating good directional solidification towards the risers. There is no evidence of solidification separation during solidification which would cause obvious shrinkage. The porosity analysis predicts no more than 2% per unit volume in the cavity at certain locations. This is not a cause for concern for two reasons:
>
> - The porosity analysis is based on the casting solidification starting from a uniform temperature. This leads to over prediction, an absolutely worst case scenario as it were.
> - Porosity less than 5% is generally not visible."

A like analysis was accomplished without the chill. Vendor comments on this analysis were:

> "This analysis was performed to show the effectiveness of the chill plate. Note in the solidification how the upper surface and lower surface of the casting become separated during the solidification. This results in a rather ridicu-

> lous amount of shrinkage porosity. The design of this casting makes the chill plate a necessity."

Figure 4-8 Porosity Comparison

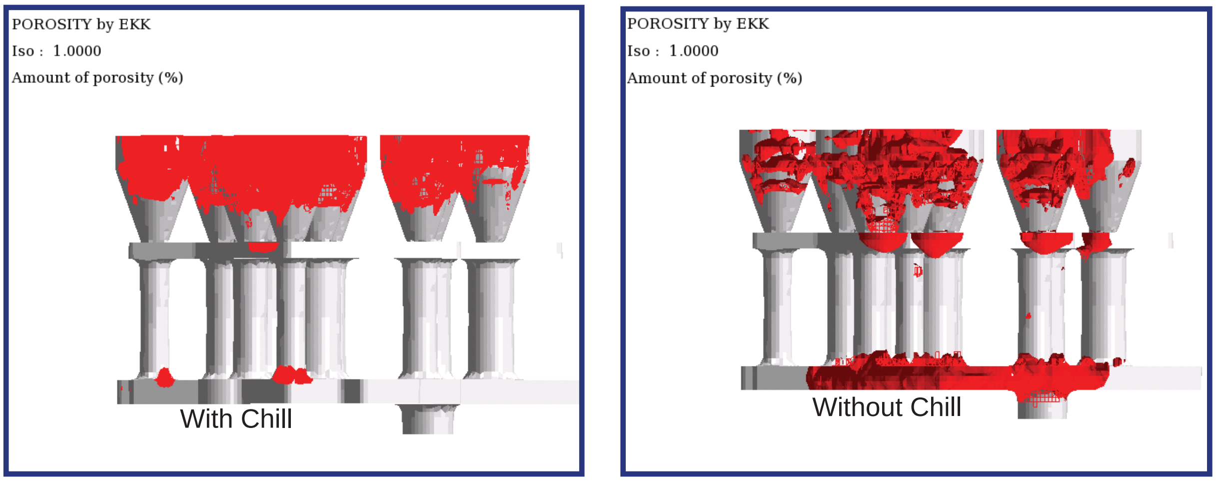


Figure 4-8 is a graphic representation of the porosity difference between using a chill plate and not using a chill plate. The red color represents potential porosity problems. As evident by the graphic, the image on the right, without chill plate, has a severe porosity potential. This demonstrates the need for a chill plate.

An In Process Review was conducted on February 17, 2006. General observations and conclusions:

1 Chill plate is very effective at forcing directional solidification

2 Size and shape of sprue likely to cause excess turbulence at the bottom of the sprue

Metallurgist, Paul Rosenthal, made the following comments for consideration:

> "I agree the severity of the chill needs to be reduced. I don't think you can increase the fill rate from what it is in the model, as it will become impossible for the metal pourer to keep the sprue "choked up". Note that neither the second or third simulation shows that the sprue is the choke, so … it's probably in the filters in each runner leg."

"To keep the cup from "overflowing," the metallostatic head pressure can be increased by adding 25 mm to the height of the cup side of the shell. This lets the pourer fill the cup during fill and cut input off before riser overflow is too severe without leaving the riser tops unfilled, as is seen in model three . The effective head pressure then becomes increased by the height above the riser top."

"The choke in the sprue bottom should allow for 1.59 Kg/Sec flow of metal and the flow rate for each runner filter should never drop below this rate; then, it's possible to hold constant the sprue pressure, and the metal velocity for the entire fill."

"The ideal input temperature should result in a constant sprue metal temperature of 705°C and should be obtainable from a tap temperature of 725°C in a properly preheated ladle."

"The casting body fills at an average rate of 1.29 Kg/Sec in 3.8 seconds against the ever increasing back pressure of the rising metal level applied in the sprue."

"A correct round tapered or square tapered sprue shape can be figured for the 239 mm height compatible with the flow rates recommended. The drop well beneath the sprue should be two times the runner vertical height."

The severity of the chill remained a concern and was going to be tested in a pour at Technikon prior to the RIA pour. The Table 4-2 represents the final results of the mold package design.

Table 4-2 Final Results of Mold Package Design

Gating Calculations Results	
Casting Weight (lbs) approx.	11
Density (Lbs/Cu In)	0.1
Metal Type	Al A356.0
# Castings Per Mold	1.0
Total Weight (lbs) approx.	25
Pouring Temperature (down the sprue)	1310°F
Pouring Time (sec)	11.0
Pouring Rate (lbs/sec)	3.49
Sprue Height (in)	8.5
Effective Sprue Height (in)	6.0
Sprue Geometry	round/tapered
Sprue Top Dimension (in)	1 3/8
Choke Dimension (in)	7/8
Pouring Basin Depth (in) approx.	2
Well Area (in X in)	3.0
Height of Pattern In Cope (in) est.	5.0
Gated At	bottom
Runner Type	u shaped
Filter	extruded non choke
Gating Ratio	1.,4.,4.
Total Runner Area (in)	2.4
Total Gate Area (in X in)	2.4

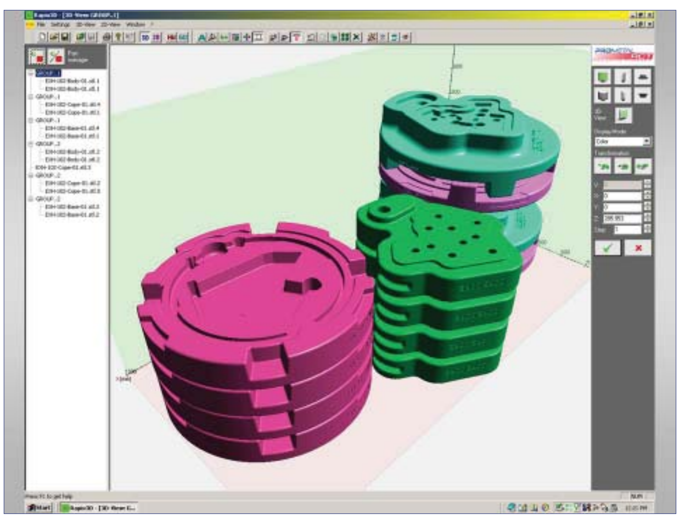
4.1. Demo Number One Production Process

<u>Digitally Printed Molds</u>

Based on the simulation results and input from the group, the molds, as designed for simulation number three, were printed by The Ex One Company. The molds were designed in such a fashion so as to include hand holds for ease of handling and identification documentation printed into the sand. Also, core placement registration posts were incorporated in the mold package to eliminate any misalignment. These features, not normally available in a conventional mold, generated positive comments from all the molders involved.

Four digital molds were printed in a single build box arranged in the shown pattern (Figure 4-9). The molds did not require the entire capacity of the build box which, in normal practice would have been filled with other part geometry molds for economic reasons. Because the molds are printed, their orientation within the build box is unrestricted. As printed for the test, two of the center cores were printed upside down and nested with the two printed right side up, thereby conserving space in the box.

Figure 4-9 Build Box Layout



The actual printing very much resembles a large ink jet printer. A print head is moved across the sand surface and prints a binder system on the applicable geometry. This is repeated layer by layer to develop the 3D geometry mold. Once the molds were printed, the non-activated sand was vacuumed from the build box and the molds extracted. The mold sections were then cleaned of loose sand with a vacuum system as shown below in Figure 4-10. A close look at the left side of the graphic reveals the part geometry in the build box. The printed geometry has a darker appearance than the unbound sand.

Figure 4-10 Mold Extraction & Cleaning

The Power Point presentation (Appendix C) is a good pictorial representation of the entire mold generation process. It provides greater detail into the entire process from CAD model to mold extraction.

Conventional Molds

By comparison, the conventional mold package requires first manufacturing the required core boxes and patterns. This included two core boxes and a two-on pattern. After several pours, the chill shape was modified to improve the solidification process. After all tooling was manufactured, the following sequence of events needed to take place to complete a mold package ready for pouring.

Figure 4-11 Feeder Core Box

The oil sand cores were hand rammed in the core boxes depicted in Figure 4-11. This process, broken down by sequential steps, included:

2. Mix sand
3. Hand fill core box
4. Compact

5. Strike off core
6. Remove loose pieces
7. Plate strike surface
8. Rollover box
9. Remove core half
10. Bake core/cool
11. Coat core with wash
12. Assemble core package (paste)
13. Store for placement in mold package

Figure 4-12 Cope Side of Pattern

Note: By gluing core halves together, fins develop on the parting line of the posts when mud washes away.

The manufactured patterns (cope Figure 4-12 and drag Figure 4-13) were mounted on insert boards. Rigging (gates/risers) were then mounted on the insert boards to feed the casting. The sequence of events required to produce the mold package included:

1. Place insert board in bolster
2. Set flask on bolster using pin registration
3. Place risers and down sprue
4. Place chills on drag
5. Mull Olivine (green) sand
6. Dispense sand and hand ram with pneumatic rammer
7. Strike off cope and drag
8. Plate drag and roll over onto carrier board
9. Pull drag pattern
10. Lift cope from pattern
11. Remove risers and down sprue
12. Apply vents and whistlers
13. Blend fillets as required
14. Remove loose sand from cope using air hose
15. Remove loose sand from drag sing air hose
16. Set pasted cores into drag prints
17. Set cope on drag and close mold package

Figure 4-13 Drag Side of Pattern

18. Paste pouring cup to cope (complete mold package shown in Figure 4-14)
19. Pour
20. Cool
21. Shakeout green sand on vibrating shake out table
22. Remove casting and core package/retrieve chill
23. Place as poured part into core knocker to remove core
24. Blast clean
25. Remove rigging
26. Post process – same for both mold processes

Figure 4-14   Complete Mold Package

4.1. Pouring Process (Conventional & Digital Molds)

Technikon Pour (Digital Mold)

Two digitally printed mold packages arrived at Technikon on March 15, 2006. Both were undamaged. The Ex One Company exercised care in packaging the molds to avoid breakage as evidenced by in Figure 4-15. The molds were palletized using foam rubber and boxed in to prevent shifting. The chill, which weighs 33 pounds, and extruded filters were shipped separately and received in good condition.

The intent at Technikon was to determine if there were going to be any abnormalities associated with the demonstration effort at RIA that could be prevented by Technikon's experience with the printed molds. Part of this concern was associated with the size of the chill. Prior to assembly, the chill was placed in the bottom core relief using a magnet. The chill did not seat completely in the bottom core relief, outsized by approximately .07 inch and required some modification. Technikon machined the chill on both sides to remove the high spots which allowed it to seat properly. Approximately .07 inch total stock was removed to make the chill parallel. This

Figure 4-15   Partial Mold Package

was not a uniform removal since the surface was not flat and witness marks were evident on the original chill surface as show in the Figure 4-16. The mold package was assembled, including chill and supplied filters, using core paste between the mold sections and weighted in preparation of the pour. The first part poured at Technikon, at 1300°F, did not fill completely. Because of this, a modification in the pouring technique was used to increase the likelihood of filling the second mold. The second pour resulted in less than completely filled risers though the part itself was completely filled. The risers farthest from the sprue filled noticeably slower and in fact did not completely fill. This supported the concern of metallostatic head pressure based on the sprue and the risers being the same height and the large mass of the chill. Because of this experience, the test group concurred on modifying the chill and adding a pouring box to increase the effective sprue height before pouring at RIA.

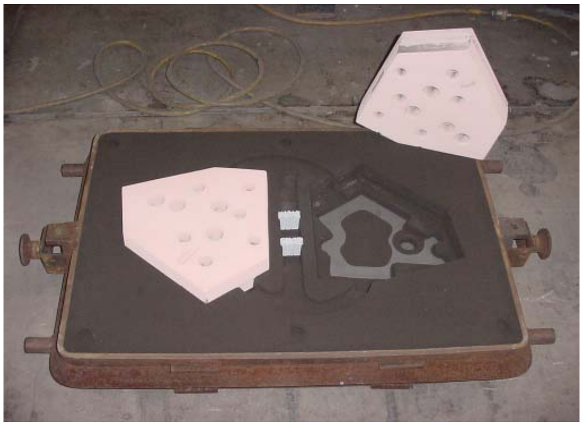
RIA Mold Assembly

On March 20, 2006, The Ex One Company, Technikon, The Practical Metallurgist and the Army all met at RIA to accomplish the two test pours. Three conventional RIA molds of the same part were poured from the same melt. One part from the accompanying pour was selected for comparison purposes and was post processed with the two demonstration parts. Prior to the pour, RIA had experimented with several configurations of chills in an attempt to reduce porosity. Based on the results of the solidification modeling effort by EKK, RIA modified a chill and incorporated it into their normal production process. The newly developed chill was used in the concurrent pour on March 20th. The

Figure 4-16 Surfaced Chill

hollowed out chill was placed in the drag with its perimeter corresponding to the part outline as illustrated in Figure 4-17. The core package was placed in the core print over the chill and the cope placed on the drag. Parts produced using this process passed the radiographic requirement.

Figure 4-17 Hollowed Chill



Based on the earlier experience at Technikon, the chill for the printed mold was modified by RIA to reduce its effect. The chill was pocketed to a thickness of 0.5 inch with an original thickness perimeter section. Figure 4-18 represents the modified chill. For the pour of the printed molds at RIA, the modified chill was placed in mold number one and the "as designed" chill was placed in mold number two. Both packages received the provided extruded filters. Digitally printed mold package number one was assembled with core paste (Figure 4-19) while package number two was assembled dry. The chill in mold number two was outsized for the receiving cavity by approximately .015 inch. This prevented the mold package from seating properly and compromised the self-sealing, self-venting and self-supporting design of the printed package. In hindsight, mold package number two should have been assembled with core paste to alleviate the compromised assembly. Both mold packages had a stan-

Figure 4-18 Modified Chill Used in Mold Number One

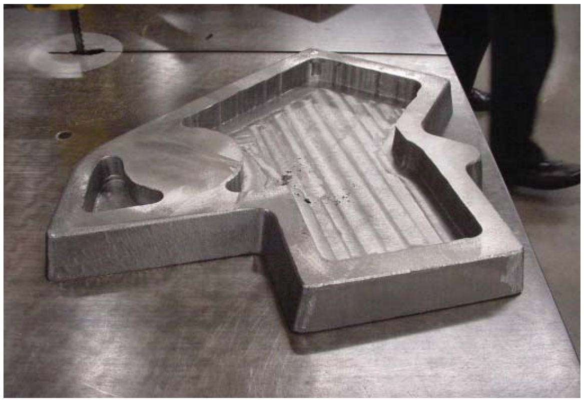


Figure 4-19 Digital Mold Assembly

dard RIA pouring box applied directly over the original sprue and sealed with core paste. The intent was to increase the effective sprue height thereby increasing the metallostatic head pressure to help achieve a desired pour time. Once assembled, weights were placed on the mold (Figure 4-20) assemblies as a means of holding them together.

Figure 4-20 Assembled Digital Package

Concurrent with the assembly of the digital mold packages, three RIA molds were assembled for pouring from the same melt. Noted for comparison purposes, the RIA mold package was two off as opposed to the single part digitally printed mold. This was intentionally done to reduce costs associated with printing and transporting larger mold packages. Each part in the RIA package had two gates feeding the part whereas the Digital package had six gates feeding the part. Also, the RIA mold incorporated foam filters as opposed to the extruded ceramic filters used in the digital package.

Melt Detail

Demo number one heat was serialized as Heat F943 – A356Al. Approximately 840 pounds of A356.0 grade aluminum was prepared with a melt furnace temperature amended to 1340°F and transferred into an aggressively pre-heated ladle for degassing. After a seven minute degassing with anhydrous nitrogen, the ladle temperature was approximately 1320-25°F. This resulted in an average mold fill temperature of 1315°F.

Pour Detail for Digital Molds

The pour began at 0820 on March 20, 2006. The two digital molds were poured first followed by three conventional RIA molds. Digital mold number one filled in 11.25 (Figure 4-21) seconds and digital mold number two filled in 11.5 seconds. The adjusted head pressure was effective in improving the fill observed at the top of the risers. The fill rate indicated that the filters were not the choke, as planned by the design. The riser farthest from the sprue on both digital molds filled markedly late, indicating a velocity mismatch, choked or unbalanced condition in the runners or gates. In the case of mold number two, the slow filling riser was actually filled by the overflowing adjacent riser. The suspect gate was later identified in the cleaning room. Mold number two ran out (Figure 4-22) after filling at the seam created by the out sized chill raising the body core. The quick action of an RIA molder, who staunched the leak with a steel rod in two places, prevented a complete run out. It was later identified that the run out was restricted to the sprue and a portion of the runner. There was no loss of material in the actual part, which was saved.

Figure 4-21 Digital Mold Number One Pour

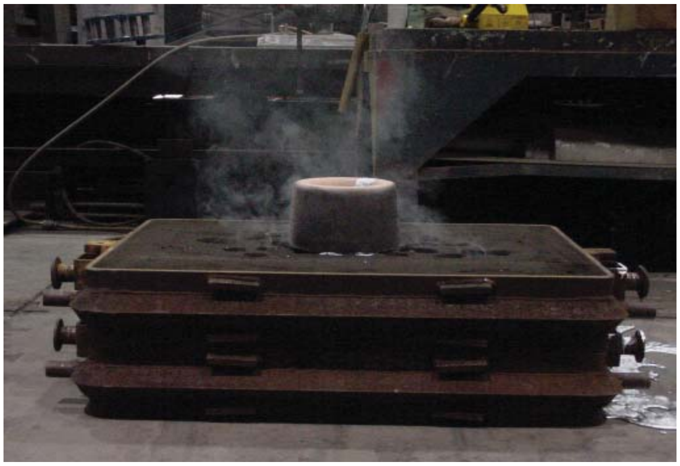
Figure 4-22 Mold Number Two Run Out

Figure 4-23 Pouring Conventional Mold

<u>Pour Detail for Conventional Molds</u>

Conventional molds, numbers three through five, were subsequently poured (Figure 4-23) from the same heat. Mold number three filled in 7.5 seconds, mold number four was miss poured and pour time not recorded and mold number five was poured in 7.25 seconds. After pouring, there was a noticeable difference in the smoke produced from the conventional mold packages as evidenced in Figure 4-24 below. In the case of the digital molds, there was no visible evidence of smoke.

Figure 4-24 Smoke from Conventional Mold Package



All the castings were left in the shells for two hours prior to shakeout. Extraction of the castings was uneventful. The digital package was easier to shake out, especially the area between the posts. Following shakeout, the parts were cleaned and the removal of the rigging was completed. Once this was accomplished, visual inspection was performed prior to radiographic inspection. The following observations were made during the visual inspection:

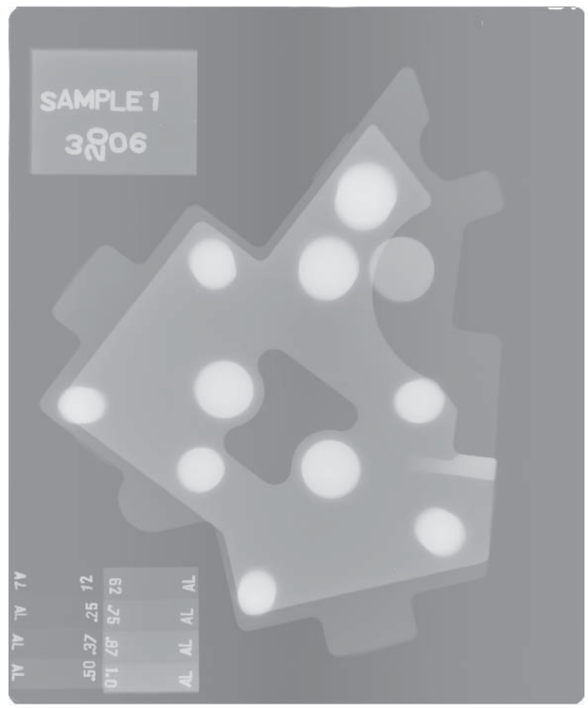
- Cold shots from the sputtering gate at high velocity against the massive chill in mold number two were observed. This was originally an item of concern in the design stage based on the size of the chill. Because of the concern, the second chill, used in mold number one, was modified and did not produce the sputtering effects seen in mold number two.
- The run-out from mold number two stopped before any casting features were impacted. The lost material was confined to the runner and filter areas of the rigging.
- The surface quality obtained on both demo castings is deemed acceptable without core wash coating, which was omitted to eliminate additional variables in the process.
- Conventional molded parts had an undesirable parting line mismatch.
- Conventionally molded parts had a better visual surface finish due to the application of core wash.
- Based on the rigging design, removal of same was less labor intensive with the

conventional package (i.e. two runners per part as opposed to six).

After visual inspection, the parts were moved to NDT for radiographic inspection against production standards.

4.1. Radiographic Results

Figure 4-25 Feeder Number One Radiograph



The technical data package required radiographic inspection per MIL-STD-2175 Class 3, Grade B in areas indicated: zones C5 and F4 Class 4, Grade C, remainder of casting (casting material only).

Both castings from molds number one and number two were free of any ratable discontinuities. The cold shots noted earlier were substantially re-melted into the bottom plate and the remaining indications in the surface were in the stock removal zone.

Both parts from the digitally printed molds met the radiographic requirements. Sample part one radiograph is shown here in Figure 4-25. The second feeder Radiograph is shown in Appendix A.

4.2. Heat Treat

The technical specifications require solution heat-treating and artificially age to temper T6 MIL-H-6088.

A decision was made between the metallurgists on the part location for obtaining mechanical test coupons from the bottom plate area of a selected casting (number one) and a companion poured RIA conventionally molded part. Test coupons were heat-treated using the following process:

- Heat to 1000°F and hold for 12 hours
- Quench in warm (approximately 80°F) water
- Natural age - Hold at room temperature (approximately 72°F) for 18 hours minimum
- Artificial age - Heat to 310°F and hold for 6 hours
- Air cool

As a point of reference, Heat F943 passed mechanicals in heat treat March 28, 2006. Actual test bar results are shown in Table 4-3.

Table 4-3 Heat F943 Aluminum Test Bar Results

	Specification Minimum	Test Bar Result
Tensile (ksi)	38	45
Yield (ksi)	28	34

Following heat treat, the coupons moved to the metallurgical lab for microstructure examination.

The two parts poured in digitally printed molds met all the technical specifications required by the drawing package. Of significance, was the difference in appearance of the post structure supporting and separating the two plate sections. Since the draft was eliminated from these structures and they were printed as one core, there was no mismatch at the post centerline as has been typical of the cope and drag mold process.

4.1. Metallurgical Analysis

A total of 45 micrographs in three formats representing seven mechanical test coupons were examined. The samples were obtained from castings at locations in the top and bottom plate sections of the first digital mold poured and the last conventional mold poured.

Table 4-4 contains all the mechanical properties results from the seven test coupons heat-treated to the T6 condition. The data shows that all tensile and yield strength values are in conformance with minimum requirements; the yield strength being the most consistent item throughout. A more variable performance was observed in the tensile results and the variability in the ductility (% elongation) from conforming to failed values is great. The traditional reason for this data performance is inclusions or mechanical defects in the samples. A coarse, non-uniform grain structure may also cause these results. A second proximate cause can also be as a result of performance in heat treatment in establishing the T6 condition, or in the solution heat treatment.

Table 4-4 Mechanical Properties Results

	Requirements Minimum	T1a	T1b	B1a	B1b	T6a	T6b	B6a	B6b
Tensile (ksi)	38	39	*	39	42	38	39	39	43
Yield (ksi)	28	33	*	32	33	33	33	32	33
% Elongation	5	2.1	*	3.1	5.1	1.9	2.7	3	7.3

Key: 1 = first digital shell poured
6 = last RIA mold poured
T or B = top or bottom plate
a or b = location within the plate listed

A comprehensive examination of the micrographs was undertaken to determine which of the possible conditions could be found. As a starting point, the four samples depicted in Table 4-5 detail the dendritic arm spacing measured in those sample micrographs. The bottom of casting one has a very small spacing while the top is very large. Casting six has more consistent top/bottom spacing but is fairly coarse compared to the bottom of casting one.

Table 4-5 Dendrite Arm Spacing Measured From Micrographs (Inches)

	B1b	T1a	B6b	T6a
l1	0.004630	0.004320	0.009330	0.018010
Cl1	5.000000	2.000000	6.000000	10.000000
SDAS	0.000926	0.002160	0.001555	0.001801
l2		0.004440	0.005520	0.009870
Cl2		2.000000	3.000000	5.000000
SDAS		0.002220	0.001840	0.001974
l3			0.004870	0.014440
Cl3			3.000000	8.000000
SDAS			0.001623	0.001805
l4			0.005770	
Cl4			3.000000	
SDAS			0.001923	
Average	0.000926	0.002190	0.001735	0.001860

Key: 1 = first digital shell poured
6 = last RIA mold poured
T or B = top or bottom plate
a or b = location within the plate listed

Comments from the metallurgist were:

> "(The) figure (labeled B1b at 50X) shows the uniform grain structure of the bottom plate in casting one as well as the attendant microporsity and inclusions from rapid cooling. It is no surprise that this area produced the best mechanical properties for casting one. (The) figure (labeled B6b at 50X) shows the fairly large size grain structure and duplex nature of the top plate sample for casting one that produced the poorest properties. Figure 4-28 demonstrates the uniform structure and cleanliness environment that produced the best properties in casting six. The poorest properties in this casting in T6a seem to be unexplained until a selective etch reveals the presence of residual coring in the high temperature areas of the grains. This was suspected in the center because that area would be the last to solidify under even colder risers that feed by volumetric "overkill". This does not mean that anything caused this from heat-treating; rather the amount of segregation occurring in the casting on solidification in the foundry was higher than normal treatment could homogenize. The relative apparent quality of the micrograph leads one to suspect a "hidden" reason for the low ductility. No other sample showed any indi-

Figure 4-26 B1b at 50X

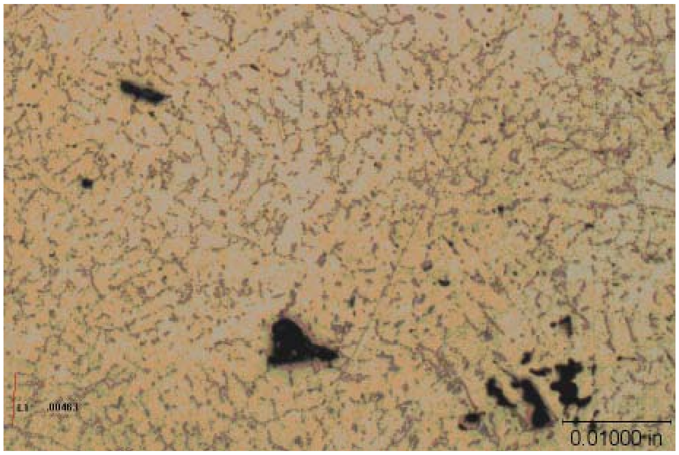


Figure 4-27 T1a at 50X

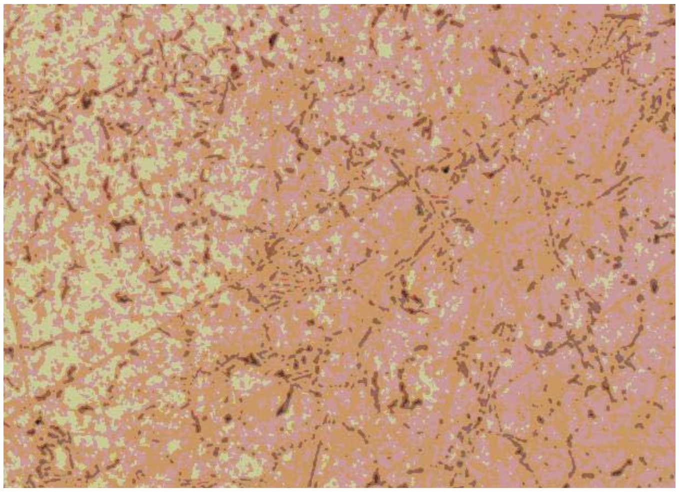
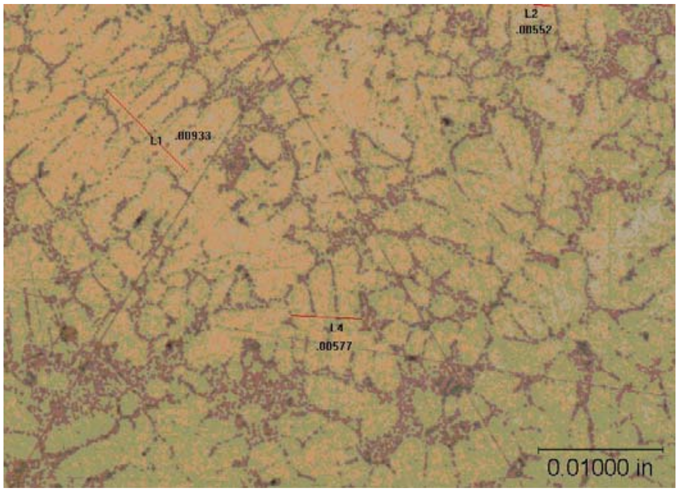


Figure 4-28 B6b at 50X



> cation that coring was present but, it was deemed not productive to check all the samples centers."

At this point, demonstration part one was considered complete. Conclusions on demonstration one are contained in the final section of this report.

5.0 DIGITALLY PRINTED MOLD DEMO TWO (M66 CRADLE P/N 7046651)

5.1. Simulation Modeling

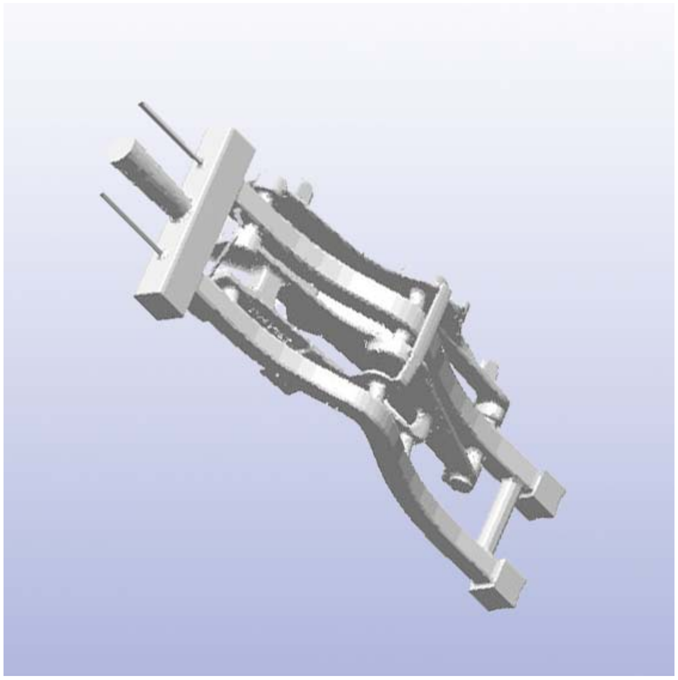
In order to demonstrate the compatibility of the digital molding process with both nonferrous and ferrous metals, a steel part was selected for the second effort. The particular part selected was the M66 Cradle, P/N 7046651, Figure 5-1. The part geometry, with an abundance of thickness transitions, has been a challenge for RIA. Using the tooling provided, RIA has not been successful in producing a serviceable part. Because of the part design, solidification needs to be controlled to minimize porosity, shrink and hot tears to produce a serviceable casting.

Figure 5-1 M66 Cradle P/N 7046651

As with the first demonstration part, a complete technical data package and a native CAD part file was supplied to the vendor. RIA also supplied digital images of the tooling that was supplied to RIA. (Note: RIA did not move forward on manufacturing this part.) This was done for information purposes only and not as a process requirement. Again, the vendor was not constrained by the current RIA process and was not required to replicate it in order to allow them the flexibility to demonstrate the full range of the capability of their technology.

The Ex One Company, via subcontractors ATD and EKK, generated a finite element model from the STL surface files using the CAPCAST automatic 3D FEM mesh generator commercially available from EKK.

Figure 5-2 M66 Model



Again, the demonstration was to be a complete process effort therefore; it included solidification modeling in an effort to increase the probability of producing a serviceable part on the first pour. Figure 5-2 is a solid model of the part with all the rigging and riser attached. This represents the "as poured" configuration. Using this model, fill and thermal simulations were made to predict outcome and evaluate rigging for potential problem areas.

5.2. Simulation Effort

Table 5-1 shows the parameters used for the sand casting simulations for the M66 Cradle

Filling analysis began with the agreed upon rigging approach. The first fill analysis was performed assuming a 10-second fill. Following are the vendors comments associated with the 10-second fill:

"It was initially assumed to try to fill the cavity in about 10 seconds. Because the fill tube and the horizontal runner don't come close to being completely

Table 5-1 Simulation Parameters for M66 Cradle

Initial Temperatures	
Steel alloy (assumed to be similar to 4130)	1610°C
Sand Mold	25°C

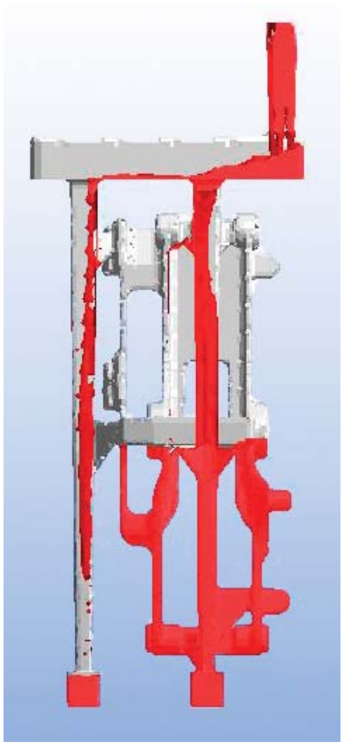
Latent Heat of fusion for Steel Alloy	
Initial Viscosity	0.05 poise
Latent Heat	65.0 cal/g
Liquidus Temperature	1500°C
Solidus Temperature	14700°C

Heat Transfer Coefficients	
Casting vs. Sand	0.2 cal/cm^2 sec C

Filling Parameters	
Desired Fill Time	3 sec.

Material Properties	Density g/cc	Specific Heat Cal/g.K	Conductivity Cal/cm sec C
Steel	7.85	0.199	0.0719
Sand	1	0.3855	0.00244

Figure 5-3 Model of Ten Second Fill

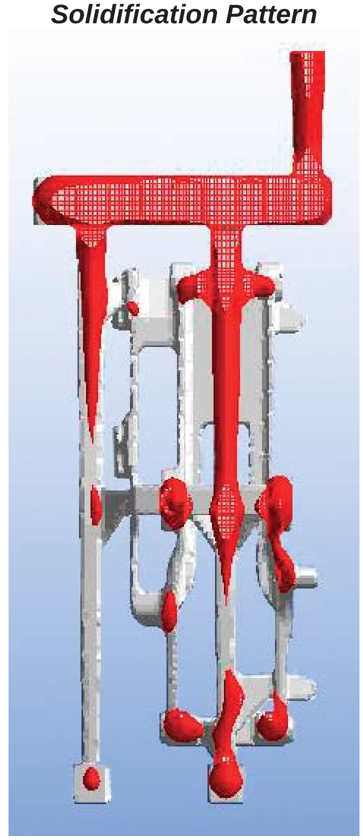


filled until the end, it can be inferred that the cavity can be filled in much less time. As it stands in this simulation, a 10-second fill renders the outside sprue almost useless. What actually happens is that fluid from the part actually begins to fill the sprue instead of vice versa."

Figure 5-3 is a visual representation of the ineffectiveness of the ten-second fill. It is clear the left sprue is nearly useless at this fill rate. Based on these results, a second fill analysis was performed using a 5-second fill rate. Vendor comments concerning the 5-second fill were:

"A 5-second fill time parameter creates a much more reasonable fill of the cavity as opposed to the 10-second fill. The side sprue is active in filling the cavity instead of the reverse. However, some hesitation does occur in the cavity at roughly two seconds. It occurs near a gate midway up the casting between the two sprues."

Figure 5-4 Model of Solidification Pattern



The second simulation improved the fill process but did reveal minor problems in one area. A thermal analysis associated with natural solidification in first and second fills was performed to evaluate the rigging. The following comments were made:

> "One solidification analysis was performed assuming a uniform casting temperature of 1600°C. The second solidification analysis imported casting temperatures from the final filling results. There are negligible differences between the 2 simulations.

The simulation based on fluid flow temperature predicts that the casting will solidify within 210 seconds.

The solidification pattern shows regions where molten metal becomes isolated in the casting during solidification (red area in Figure 5-4). These regions are potential shrink growth regions and will negatively alter the mechanical properties of the casting in those regions.

The Niyama criteria analysis gives more definitive locations of potential trouble areas.

Faster cooling rates and more directional solidification will improve overall casting quality. Unfortunately, the casting design contains alternatively thick and thin regions which make directional solidification problematic. The numerous thick sections make the possibility of precisely located chilling difficult as well.

Many of the thick problematic sections are located near sprue gates. Widening these gates may serve to delay the freeze of these gates and allow for more solidification flow into the runner."

Based on the previous analysis, the group agreed that some chilling was required to achieve a good part. A thermal analysis was run using natural solidification in a simulated zirconium mold to help the chilling effects. Comments from this effort were:

> "This simulation crudely tries to capture the effect of a convective sand material inside the sand mold. In this case, the Zirconium completely surrounds the casting and sprue to a one inch thickness. The chilling effect is quite extensive and results in a much improved solidification pattern than in the nominal configuration. The thick sections solidify relatively quickly and there are more instances of solidification flow into the sprue."

The working group agreed that incorporating chromite inserts would be the most practical method to help the solidification process. Slight modifications were also made in the rigging system. Chill locations were agreed upon and a simulation was run. Comments from that simulation were:

> "Chromite inserts were simulated to help solidify the thick sections more quickly. Geometrical changes were also made to the sprue. The solidification pattern is improved in this design. There is much less isolated shrinkage in the heavy sections and better directional solidification when compared to the initial design. The Niyama criteria analysis also shows an improvement over the previous design. The upper half of the casting overall shows more improvement than the lower side. It seems though that extra chilling emphasis may need to be placed on the outer casting bosses (bosses not in between two sprues). Even with the current chilling scheme, defects in these bosses might be stubborn."

Three-Second Fill Vendor comments:

> "A 3-second fill is quite possible with this design. Although the far sprue is not as inactive as in the slower simulations, there still is a good amount of fluid dropping into the casting cavity causing excess turbulence."

Based on this simulation, the working group agreed that slight modifications needed to be incorporated in the runner system. These were simple changes which allowed an almost immediate additional three-second fill simulation.

Second Design Iteration (Three-Second Fill) Vendor comments:

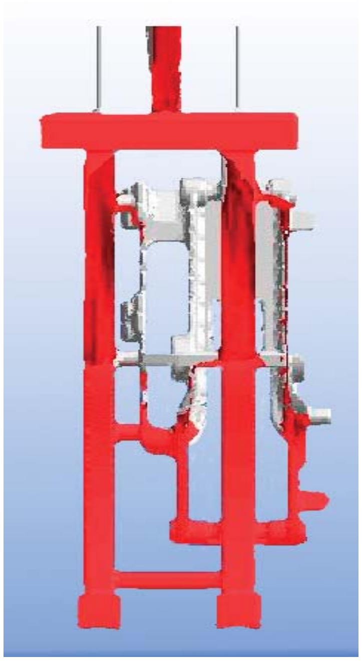
> "There is definitely less dropping fluid in this design when compared to the previous design. The filling is much more even up the casting and not as violent. There can be some improvement made to the downsprue as well, though. Note how the fluids momentum carries is in a downward parabolic arc as it initially falls through the sprue. This is especially noticeable in the center sprue. It is recommended that the top of the sprue be curved to match the fluid stream. The current configuration can lead to excessive oxide inclusion."

After this simulation, the down sprue was moved to the center of the horizontal runner bar to facilitate more even filling. A third design iteration was accomplished and another three second fill simulation accomplished. Vendor comments were:

> "The most notable issue with this design iteration is the dripping of down into the casting on the right side (when looking at the front view). The changes to the runner to help the casting fill more evenly from top to bottom seem to work as intended for the most part. There are occurrences of premature "seepage" from some upper gates; the one that must be addressed is the upper right gate. The turbulence of all the fluid dropping from this gate will most likely cause problems. Moving the main pour basin closer to this right sprue might help to lessen the fluid inertia, thus lessening the unintentional flow into the gate somewhat. Another possibility may be to lower the casting down along the sprue by an inch or more so that the fluid no longer has so much horizontal inertia when it passes by the gate."

Noticeable in Figure 5-5 is the relocation of the down sprue and the tie bar that was added between at the base of the two vertical runners.

Figure 5-5 Model of Relocation of Down Sprue



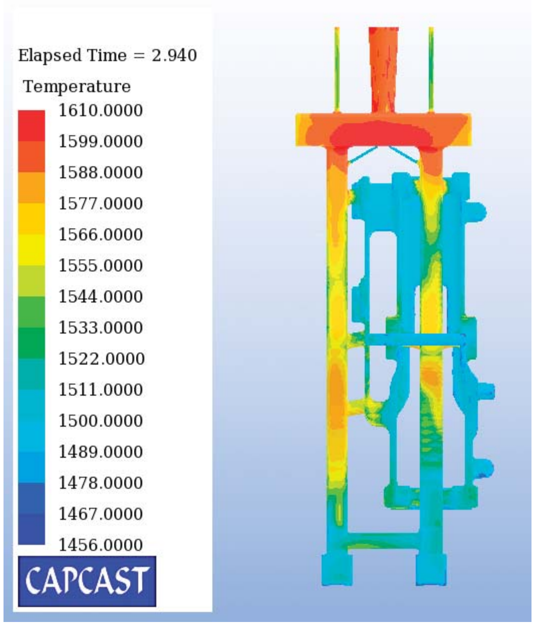
The thermal portion of this simulation resulted in the following comments:

> "The thermal benefits from this latest design are mixed. In some locations, namely the middle bosses, the Niyama criteria analysis show some improvement from the previous design. However, in other locations, chiefly the upper right gates, the directional solidification is reduced somewhat causing Niyama criteria analysis to show a larger possibility of defect problems in those areas. Increasing the cross sectional area of the gates may be necessary to bring back a degree of proper solidification."

Minor changes were made in the rigging design after this simulation in an attempt to correct the new problems encountered. The fourth design iteration (three-second fill) slightly complicated the existing problem as evidenced by the following vendor comments:

> "Unfortunately, the new gate design will cause a dripping effect from the left side gate now. This gate will need to be either narrowed, moved towards the middle (width-wise) of the downsprue, have the draft removed, or a combination of all three."

Figure 5-6 Final Thermal Simulation



This resulted in a fifth design iteration that seemed to cure all the concerns associated with solidification. This became the model that ATD converted into a mold package for printing. Figure 5-6 represents the final thermal simulation for the M66 cradle. The three-second fill (the part is actually full before three-seconds) results in a temperature gradient high enough to avoid misruns.

5.3. Cradle Production Process

Conventional Molds

Rock Island was supplied patterns by the customer for the M66 Cradle. RIA was unsuccessful in producing a serviceable part using the supplied tooling. Since all the pattern/core boxes were supplied, there was no comparative data available on the tooling development process. RIA was requested to return the tooling to the customer and design new tooling for the part. At this point in time, this requirement has not been formalized and RIA is in the preliminary design phase. Because of this, there was not a concurrent pour as with the first demonstration effort. This eliminated the possibility of a side-by-side comparison. The bottom line to the conventional effort with supplied tooling was the inability to produce a serviceable part. It was after this effort that the foundry working group decided to tackle the M66 as a demonstration part.

Digitally Printed Molds

Based on the review of the working group and all the process modifications, the fifth simulation iteration was agreed upon as the file to print. ATD used this file to develop the mold package. The mold package was designed to be self-supporting and included text on individual components (i.e. cores) to identify them. The self-supporting design included interlocking parts with wedges to hold them in place. Because the part geometry necessitated the need for chills to support directional solidification; cavities were designed into the mold package to receive the chills. The molds were printed on an S-15 RCT machine in Irwin, PA and shipped to RIA for pouring. The chills were hand rammed in core boxes since they were of a different medium (i.e. chromite sand). Both molds and all chills were received at RIA September 6, 2006, in good condition. For ease of shipping and to minimize the potential for shipping damage, the molds were assembled and packaged in foam rubber. As in the previous demonstration, The Ex One Company took extreme care in packaging to ensure molds were delivered undamaged.

Digital Mold Assembly

On September 12, 2006, The Ex One Company, Technikon, The Practical Metallurgist and the Army all met at RIA to accomplish the M66 cradle pour. The printed mold packages were disassembled for cleaning and the insertion of chills prior to assembly. Figure 5-7 shows the mold being air cleaned prior to placing the chills. Once all the components were cleaned, chromite chills were placed in the appropriate cavities using core paste where necessary. In Figure 5-8, the chromite chills are evident by their darker color as compared to the mold. Once all the chills were placed, the core sections were added to the mold package (Figure 5-9). After core placement, the sprue section of the mold package, acting as a locking cap, was added to complete the package. The mold package had a standard RIA pouring box applied directly over the original sprue and sealed with core paste. Since the foundry operating personnel were not accustom to self-supporting printed molds and were concerned about their stability, it was collectively decided to band the packages to ensure there would not be any run outs.

Figure 5-7 Mold Cleaning

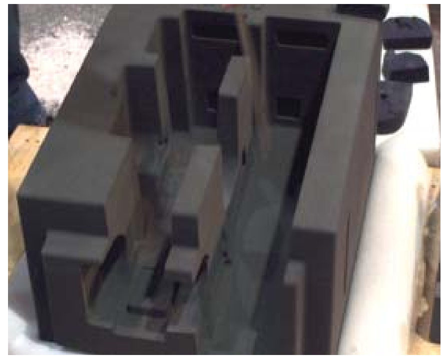
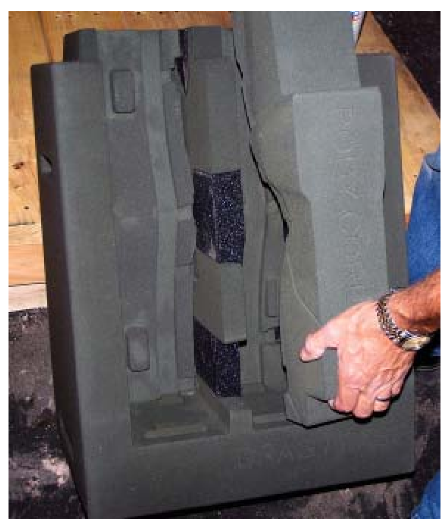


Figure 5-8 Mold with Chills

Figure 5-9 Core Placement



5.4. RIA Pouring (Digital Mold)

<u>Melt Detail</u>

Demo Number Two Heat was serialized as F878 – Class 4 Steel

A five ton electric arc furnace was used to produce a three ton class 4 steel heat for transfer to a three ton ladle. This size furnace was used because of the requirement to pour several other parts that required the same chemistry. A continuous slag run-off practice was employed to produce a heat chemistry in the acceptable range established for class four steel. The block-to-tap time was 10:40 minutes, slightly over the maximum allowable 10 minutes, was troublesome because of the rain which maximizes re-acquisition of hydrogen into the bath.

The chemistry for this heat is shown in Table 5-2. The furnace was tapped at a temperature of 3014°F and resulted in a ladle temperature of 2992°F.

Table 5-2 Heat Chemistry

	Target	Ladle
C	0.25-0.30	0.28
Mn	0.50-0.65	0.53
P max	0.015	0.01
S max	0.015	0.015
Si	0.45-0.55	0.44
Ni	0.47-0.55	0.54
Cr	0.47-0.55	0.46
Mo	0.47-0.55	0.52
Cu	- - -	0.16
V	- - -	0.018
Al	0.030-0.065	0.051

Pour Detail

A standard keel block of test bars was poured as stand alone tests for mechanical properties. A full line of sand spade castings were poured prior to filling the M66 molds, which were poured at an estimated temperature of 2950°F. Digital mold number one filled in 5.4 and digital mold number two filled in 5.7 seconds, which calculates to a poured weight of 65 and 68 pounds respectively. Figure 5-10 is digital mold package number two being poured. A bottom pour ladle was utilized for the pouring.

Figure 5-10 Digital Package Number Two Pour

Figure 5-11 illustrates the bound mold package after it was poured. Extraction of the castings was uneventful. Figure 5-12 represents the as poured part (i.e. rigging still attached). The castings were sent to the cleaning room for sand removal and blasting. Once cleaned, the castings were photographed and visually inspected. Visual inspection revealed small areas of hot tears (Figure 5-13), mostly at section changes. Observations were identified for weld repair after rigging was removed. Standard class 4 steel parameters and materials were used for the repair.

Figure 5-11 Poured Mold

After visual inspection, the parts were moved to non-destructive testing (NDT) for inspection against production standards.

Figure 5-12 As Poured Cradle

<u>Inspection</u>

The part drawing requirements do not specify any radiographic or magnaflux inspection requirements for the M66 cradle. Both prototype castings passed visual inspection for commercial quality as delivered from the cleaning room (i.e. serviceable parts assuming geometry is accurate). Nevertheless, both parts were

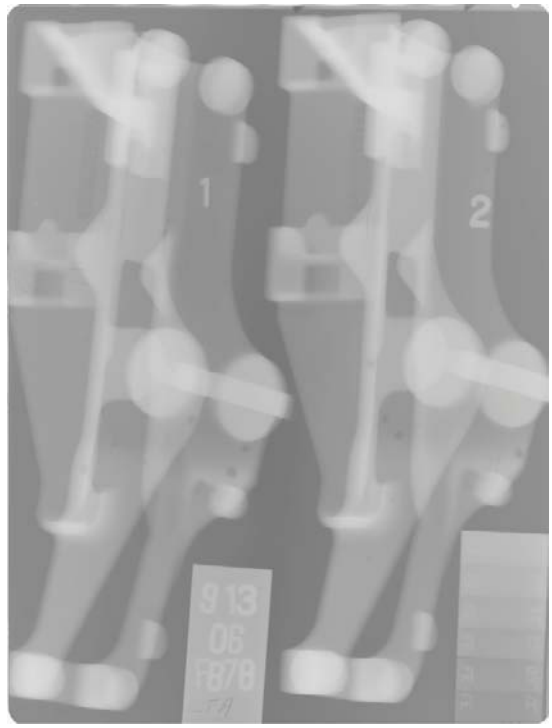
Figure 5-13 Cradle Hot Tears

subjected to both radiograph and magnaflux inspection based on a "first article" practice of RIA.

During radiographic inspection, indications of vitrified inclusions and/or hydrogen gas accumulations were observed in what all observers agree were acceptable areas and concentrations. These were well away from chromite sand inserts and solidification control of boss areas. Noticeably absent were indications of interdendritic shrinkage which plagued the previously examined Defense Logistics Agency (DLA) castings. Figure 5-14 is radiographs of the M66 cradle. Additional radiographs are shown in Appendix A. The small inclusions, mentioned earlier, are visible as slightly darker spots.

Figure 5-14 M66 Cradle P/N 7046651 (X-ray Shot 3)

M66 Cradle P/N 7046651 (X-ray Shot 3)



The cradles were magnaflux inspected according to military specifications. Areas containing linear indications which were not apparent because of their tightness at the surface were indicated but are assessable and repairable by standard methods. They do not show up on radiographic plates. These areas were marked for delivery to the cleaning room for weld repair.

Post Processing

At the time of this report, the M66 Cradle prototype parts have not completed the required post processing. The parts need to be heat treated to the 105/85 class per ASTM A148. Test coupons should also be heat treated with the castings. The coupons will then require mechanical testing.

After heat treatment, the part surfaces should be re-inspected and the part geometry should be checked for accuracy per the technical data package.

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6.0 CONCLUSIONS

Eliminating the need for hard tooling in the casting process has huge implications on cost as well as lead time. Traditionally, tooling has required significant investment in lead time, skilled labor and cost. The ability to produce serviceable casting on the first pour is directly related to the quality of the tooling design, precision of the tooling built and the control of the casting process. It is not uncommon for first pours to require changes in tooling design to reduce or eliminate casting defects and optimization of the process. These changes can be extensive and expensive if they involve significant tooling changes. Reducing or eliminating these costs as well as shortened lead times are the hallmark of the digital process.

Based on the two demonstration parts produced with digitally printed mold/cores for the RIA effort, the following advantages were realized:

- Eliminated the need for high-cost tooling while in the prototype/first article effort. Tooling can be expensive, relies on skilled labor that is in short supply and tends to extend lead time to production.
- Mold printing is driven directly from a CAD model therefore; design changes can be quickly and inexpensively incorporated into subsequent iterations for optimizing the casting process. As noted earlier in this report, multiple iterations in tool design were accomplished and simulated prior to production.
- Producing in a digital environment allows new design freedoms not available in conventional processes. Based on simulation modeling, changing rigging design on the M66 Cradle to a complicated geometry to help filling and solidification was only a CAD change. The printed geometry would have been an extensive and expensive change in hard tooling. This again optimized the process before an investment is made in hard tooling for longer production runs.
- Unique serialization for prototype parts can easily be added to each part thereby insuring unique identification through post processing. This ensures any changes made in the process are identified to a unique part when analysis is made towards optimization of the production effort.

- For infrequently produced parts, only the storage of a digital file is required. If in the future the same part is again required, only the digital file has to be retrieved and compared to the current technical data package for latest revisions. If there are revisions, only the CAD model requires changing. In the case of hard tooling, an inventory has to be maintained to retrieve the tooling from storage. Once retrieved, the tooling needs to be made serviceable and compared to the latest technical data package for applicability. If there is a drawing revision, the hard tooling would have to be modified to meet the new requirement. This is not an uncommon situation for DOD requirements especially when dealing with legacy systems that have been in inventory for decades and have gone through numerous design configuration changes. The digital process allows producing a family of parts from one design to meet this sort of requirement. Design iterations can be specific to original production lots therefore; multiple designs of the same part can be required. In the world of hard tooling, this would require multiple tools and increases storage and identification.

Compared to the conventional foundry process, there will be some cost break even point depending on tooling required and the number of parts required to be produced. With conventional tooling, obviously the more parts required the less per part the tooling cost since it is a direct cost associated with making even a single part. Figure 6-1 is a graphic representation of the cost avoidance/savings achieved using digital mold printing technology. For prototypes or limited production there is a significant difference in cost. As the production quantity increases and the cost of tooling are amortized over more parts, the cost per part becomes less. Obviously, at some quantity, it becomes more cost effective to produce hard tooling.

Figure 6-1 Cost Avoidance/Savings Chart

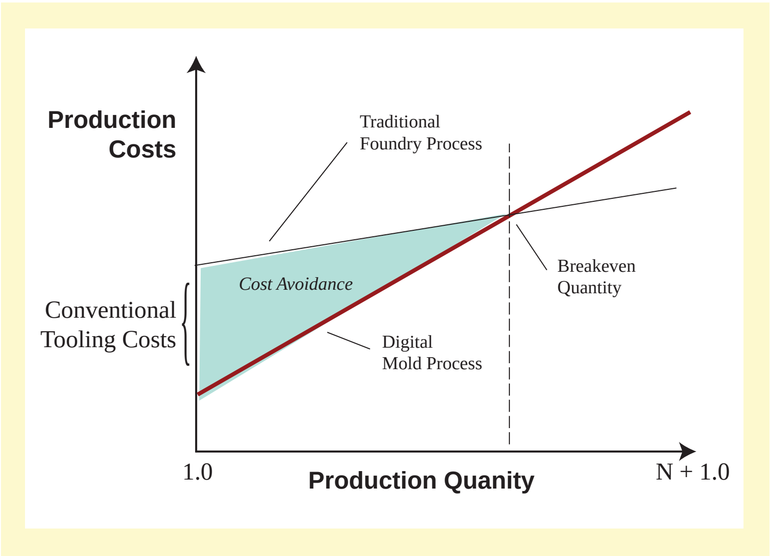
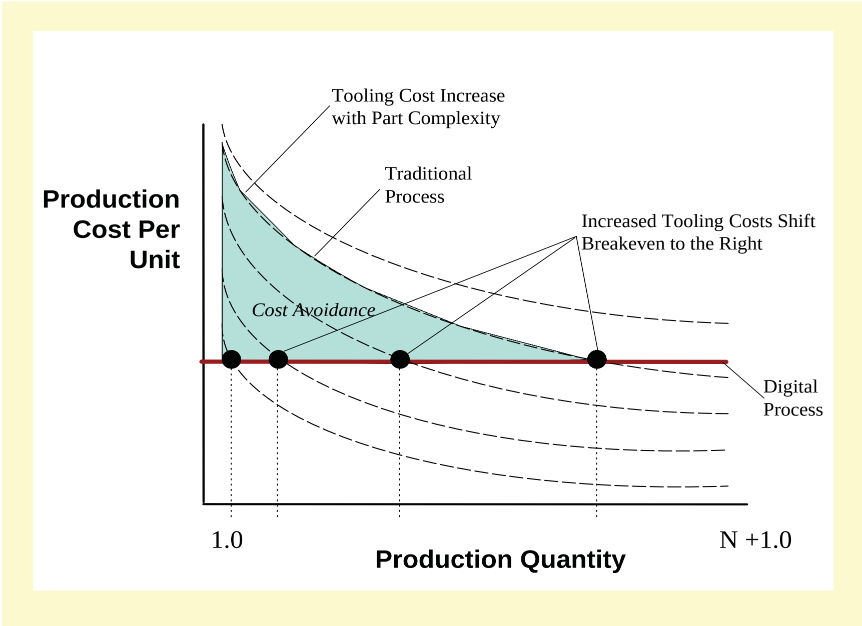


Figure 6-2 ***Complexity Breakeven Chart***



Another area of initial savings that can be significant is related to multiple iterations required to produce a serviceable part. In many instances, serviceable complex parts are not produced on during the first pour. Tooling modifications can be costly and time consuming. With the digital mold printing process, only a CAD model change is required and a new mold printed.

As with mold patterns, core boxes get complex and drive up cost considerably. In many instances, multiple boxes are required to produce a single core (i.e. halves are pasted together to form a single core). Utilizing the digital printing process, complex cores can be manufactured with the same ease of a simple core. Again, complexity can drive potential cost savings as depicted in the Figure 6-2 graph.

The digital mold printing technology is not without its drawbacks. Currently the technology is such that the required equipment needs to be housed in a controlled environment for both temperature and humidity. Such an environment is traditionally not found in an operating foundry. This is not to say that future foundries may look considerably different than today's.

Process material recycling is also an issue. At this time, the excess/used sand is not recycled as is the practice in conventional foundry processes. This adds considerable cost to the process and is an area that deserves considerable attention. If process material recycling can be practical, operating cost could be reduced significantly and the break even quantities would move to the right.

Like most new technologies, the initial capital investment is substantial and will hopefully decrease over time as the technology matures.

Based on the RIA demonstration effort, there is a niche market that could greatly benefit from the digital mold/core printing technology. Low quantities of complex parts, prototypes and critical single part requirements fit nicely into this niche. RIA tends to operate in this sort of environment on a daily basis. Since RIA cost data was not shared in the demonstration effort, an exact cost saving on the demonstration parts is not available. It was apparent that from viewing the process that a 50 % reduction in lead time would be a conservative estimate. In the case of the M66 Cradle, RIA was unsuccessful in producing the part with the provided tooling. Using the digital printed mold process resulted in serviceable parts on the first pour.

It is recommended that RIA do a complete cost comparison on the demonstration parts and determine under what circumstances the new process would benefit their efforts. Since the initial capital investment is significant, RIA should also consider subcontracting complex requirements when the need arises. At some point in the future, the digital process should be considered as a technology insertion project to better meet critical DOD requirements.

APPENDIX A INSPECTION RADIOGRAPHS

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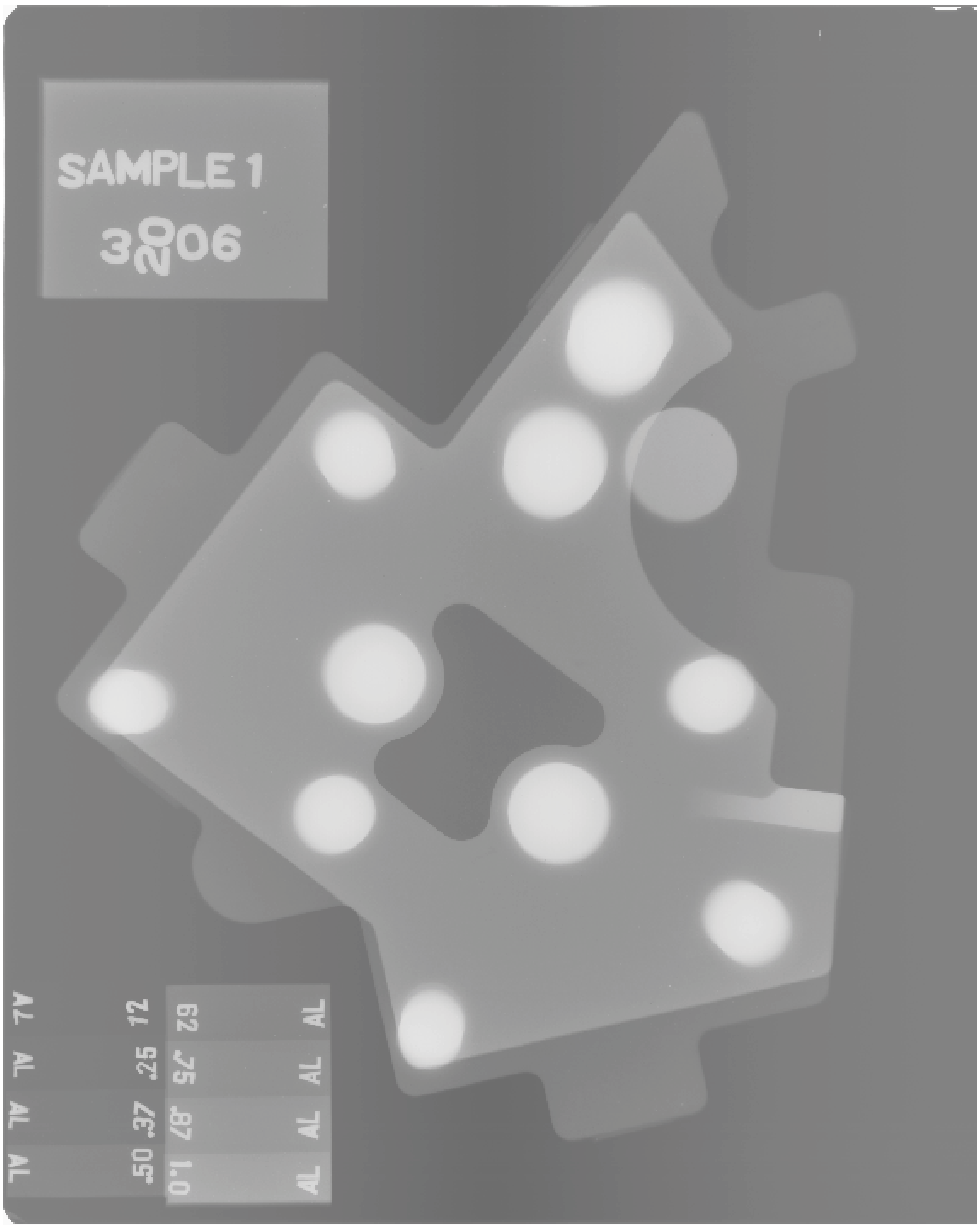
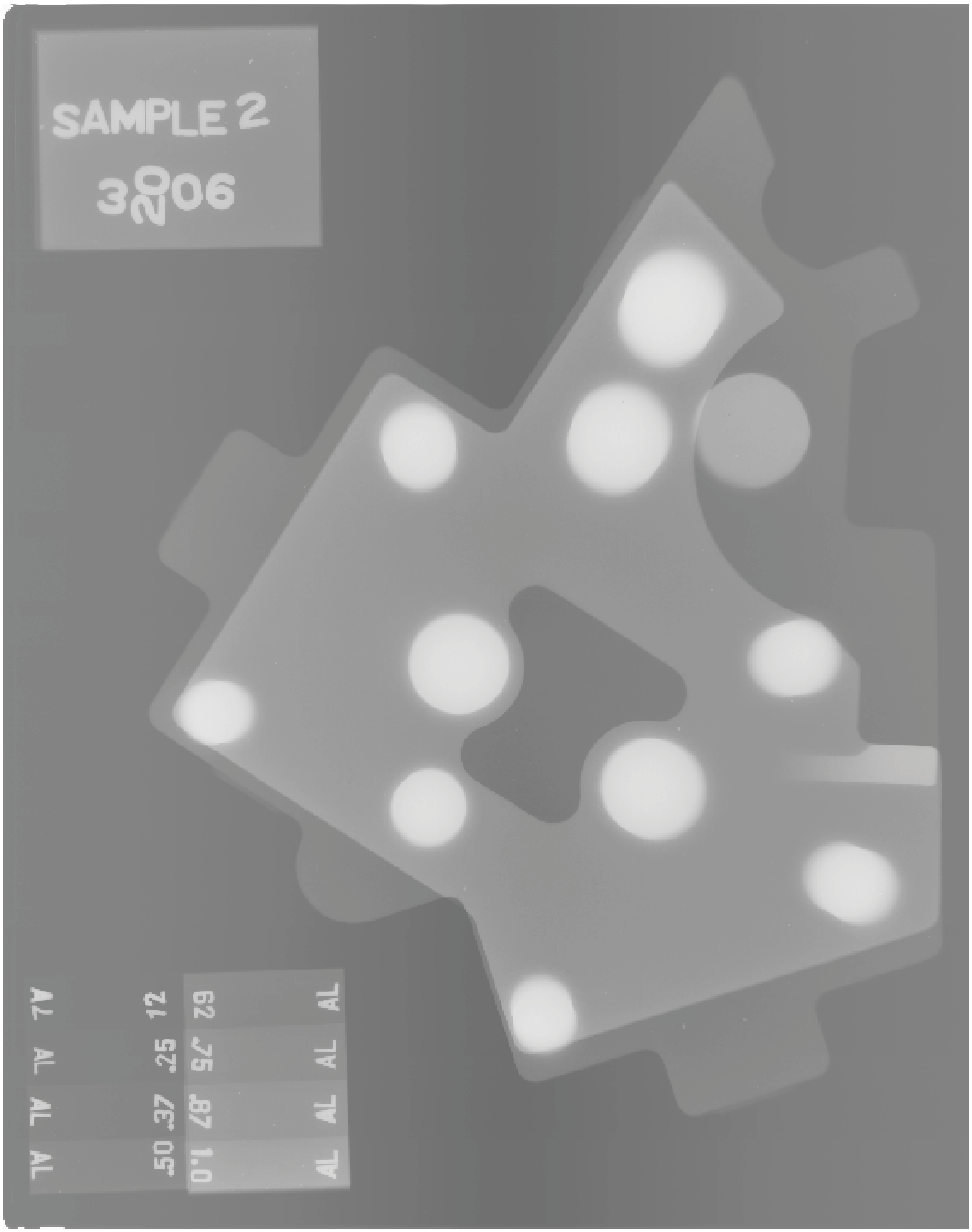
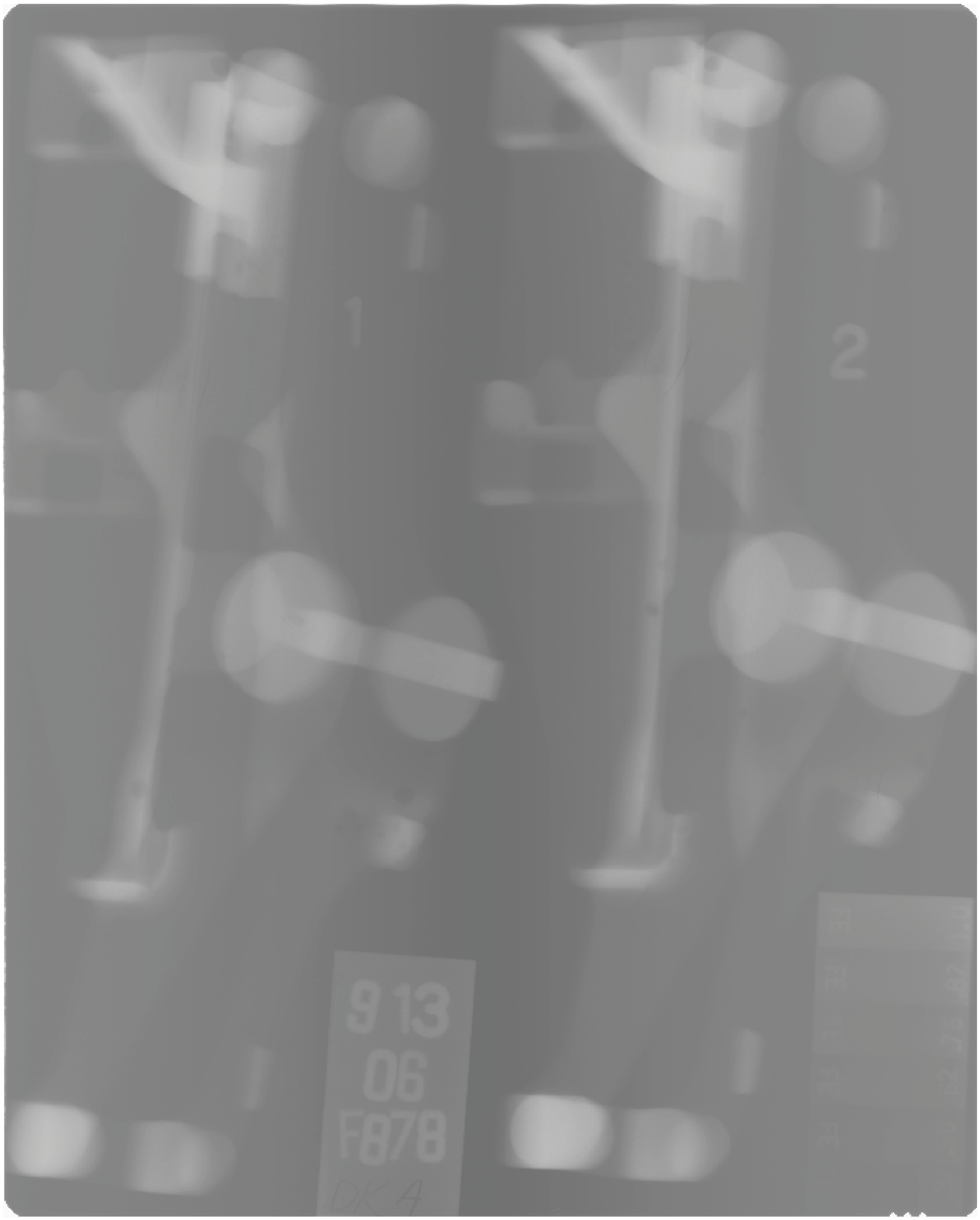
Radiograph Forward Feeder – Sample 1



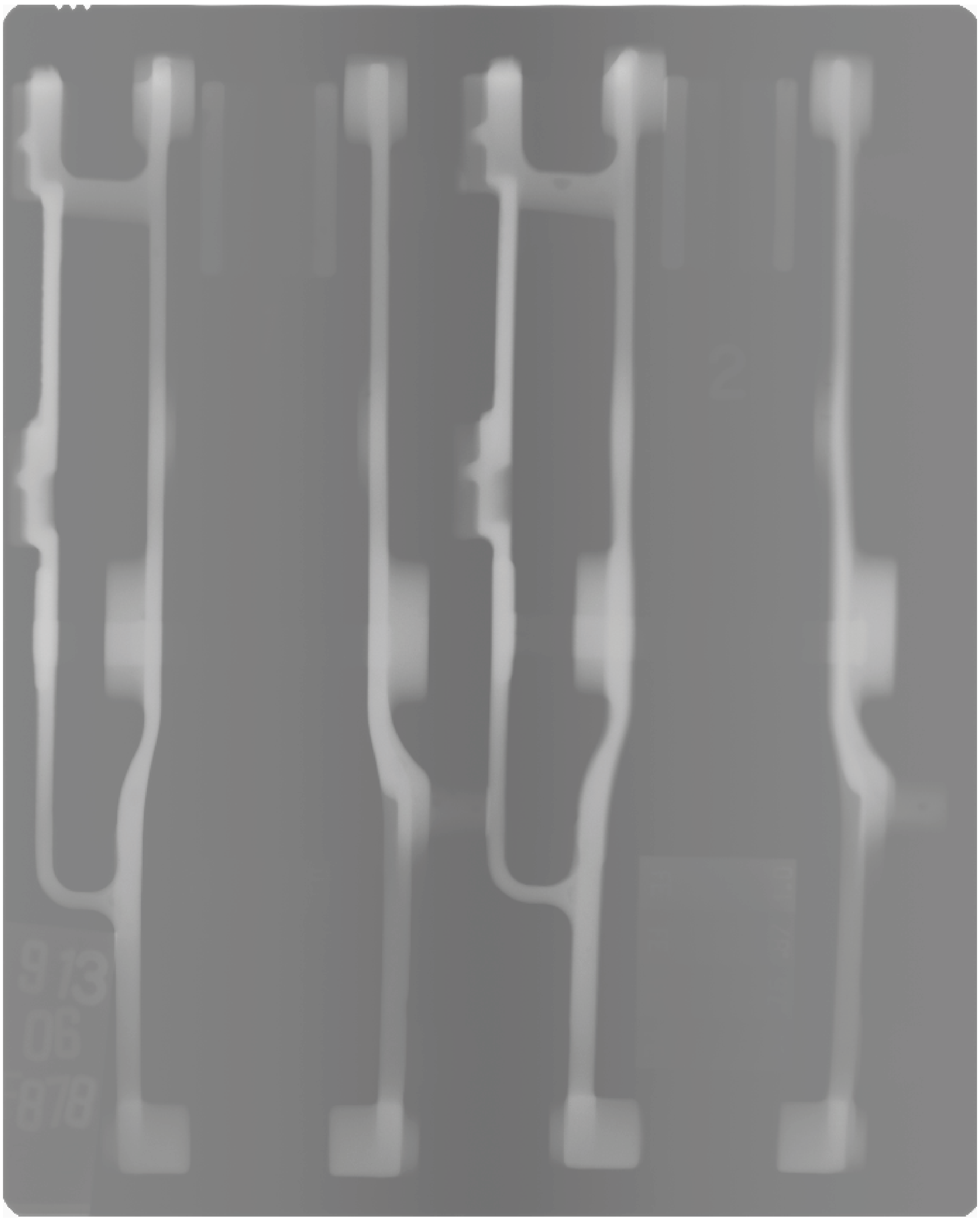
Radiograph Forward Feeder – Sample 2



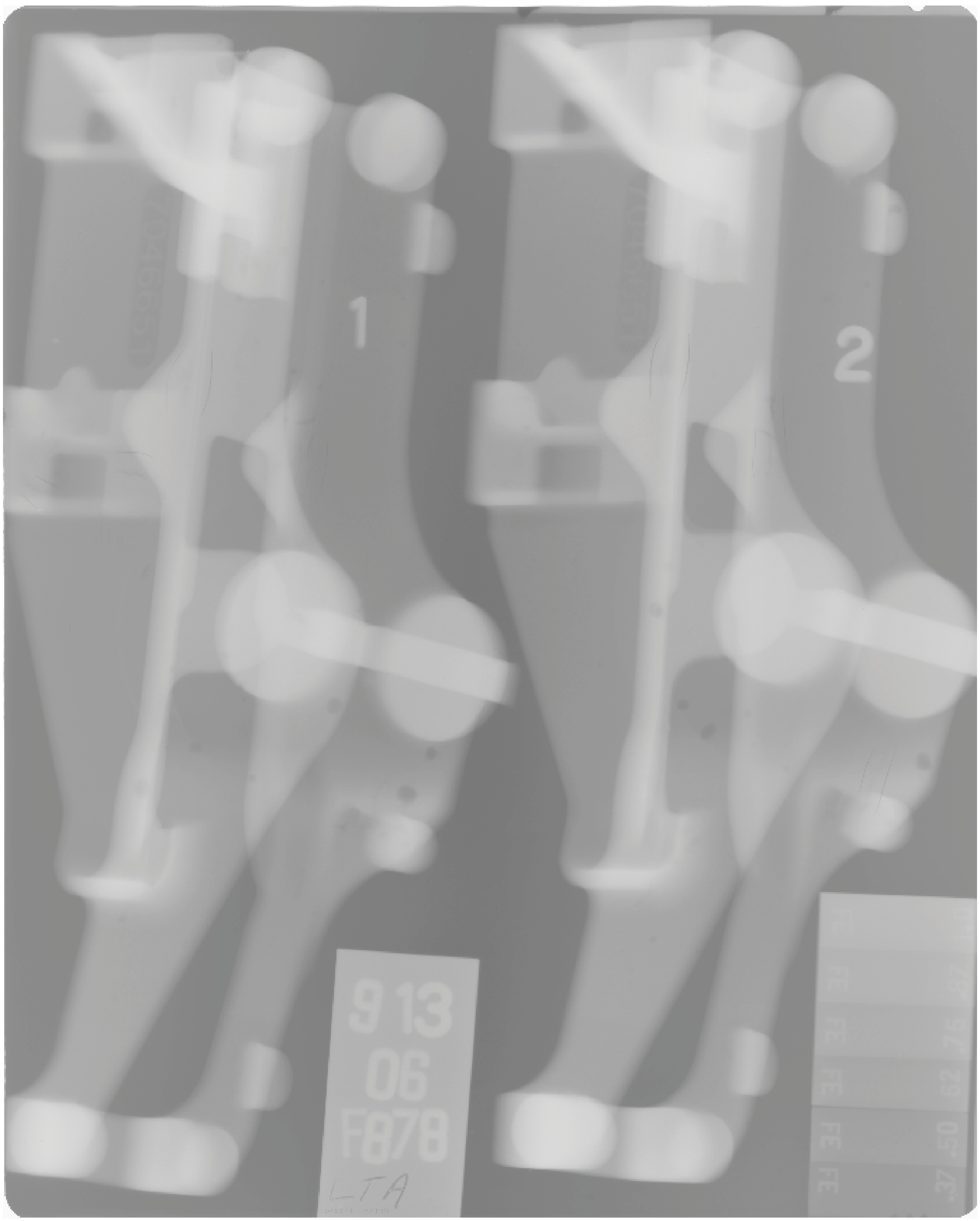
M66 Cradle P/N 7046651 (X-ray Shot 1)



M66 Cradle P/N 7046651 (X-ray Shot 2)



M66 Cradle P/N 7046651 (X-ray Shot 3)



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APPENDIX B MSDS SHEETS FOR MATERIAL USED IN DIGITAL PROCESS

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EXTRUDEHONE®
PROMETAL® RAPID CASTING TECHNOLOGIES RCT

Material Safety Data Sheet

Material Name: RCT Activator FA001 **ID: FA001**

* * * Section 1 - Chemical Product and Company Identification * * *

Manufacturer Information

Extrude Hone Corporation
1 Industry Blvd.
P.O. Box 1000
Irwin, PA 15642
Phone: (724) 863-5900
Fax: (724) 862-8759

* * * Section 2 - Composition / Information on Ingredients * * *

CAS #	Component	Percent
104-15-4	p-Toluenesulfonic acid	50-70
7664-93-9	Sulfuric acid	<2

Component Information/Information on Non-Hazardous Components

This product is considered hazardous under the criteria specified in 29 CFR 1910.1200 (Hazard Communication Standard) and the Canadian Workplace Hazardous Materials Information System (WHMIS).

* * * Section 3 - Hazards Identification * * *

Emergency Overview

DANGER. CORROSIVE. Product is a dark brown liquid with a typical odor. May cause severe irritation or burns to the eyes, skin, gastrointestinal tract, and respiratory system. This product contains a component that may cause cancer. This product contains a component that reacts with water.

Potential Health Effects: Eyes

This product is severely irritating to the eyes and may cause eye burns. May cause blindness.

Potential Health Effects: Skin

This product is severely irritating to the skin and may cause burns.

Potential Health Effects: Ingestion

This product may be harmful if it is swallowed. Ingestion may produce burns to the lips, oral cavity, upper airway, esophagus and possibly the digestive tract.

Potential Health Effects: Inhalation

This product is severely irritating to the respiratory system.

HMIS Ratings: Health: 3 **Fire:** 1 **Physical Hazard:** 2

Hazard Scale: 0 = Minimal 1 = Slight 2 = Moderate 3 = Serious 4 = Severe * = Chronic hazard

* * * Section 4 - First Aid Measures * * *

First Aid: Eyes

Immediately flush eyes with water for at least 15 minutes, while holding eyelids open. Seek medical attention at once.

First Aid: Skin

For skin contact flush with large amounts of water while removing contaminated clothing. Get medical attention. Wash contaminated clothing before reuse.

First Aid: Ingestion

If material is ingested, immediately contact a physician or poison control center. DO NOT induce vomiting. Never give anything by mouth to a victim who is unconscious or is having convulsions.

First Aid: Inhalation

If inhaled, immediately remove the affected person to fresh air. Seek medical attention.

Material Safety Data Sheet

Material Name: RCT Activator FA001 **ID: FA001**

* * * Section 5 - Fire Fighting Measures * * *

Flash Point: Not applicable
Upper Flammable Limit (UFL): Not available
Auto Ignition: Not available
Rate of Burning: Not available
Method Used: Not available
Lower Flammable Limit (LFL): Not available
Flammability Classification: Not applicable

General Fire Hazards
The product itself does not burn.

Hazardous Combustion Products
Sulfur oxides, carbon monoxide, carbon dioxide and other hydrocarbon fragments.

Extinguishing Media
Water, carbon dioxide or regular dry chemical.

Fire Fighting Equipment/Instructions
Wear full protective clothing, including helmet, self-contained positive pressure or pressure demand breathing apparatus, protective clothing and face mask. Prevent electrostatic charge build-up by using common bonding and grounding techniques.

NFPA Ratings: Health: 3 **Fire:** 1 **Reactivity:** 2
Hazard Scale: 0 = Minimal 1 = Slight 2 = Moderate 3 = Serious 4 = Severe

* * * Section 6 - Accidental Release Measures * * *

Containment Procedures
Stop the flow of material, if this is without risk. Block any potential routes to water systems.

Clean-Up Procedures
Collect spilled material with an inert absorbent such as sand or vermiculite. Place in properly labeled closed container.

Evacuation Procedures
Evacuate the area promptly and keep upwind of the spilled material. Isolate the spill area to prevent people from entering. Keep out of low areas.

Special Procedures
Wear appropriate protective equipment and clothing during clean-up.

* * * Section 7 - Handling and Storage * * *

Handling Procedures
Do not get this material in contact with skin or eyes. Do not ingest product. Do not breathe in vapors or mists of this product. Use this product with adequate ventilation.

Storage Procedures
Keep separated from incompatible substances. Keep this material in a cool, well-ventilated place. Keep container tightly closed.

* * * Section 8 - Exposure Controls / Personal Protection * * *

Exposure Guidelines
A: General Product Information
Refer to published exposure limits. Use effective control measures and PPE to maintain worker exposure to concentrations that are below these limits.

B: Component Exposure Limits
Sulfuric acid (7664-93-9)
ACGIH: 0.2 mg/m3 TWA (thoracic fraction)
OSHA: 1 mg/m3 TWA
NIOSH: 1 mg/m3 TWA

Engineering Controls
Use general ventilation and use local exhaust, where possible, in confined or enclosed spaces. Eyewash fountains and emergency showers are recommended.

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Material Safety Data Sheet

Material Name: RCT Activator FA001 **ID: FA001**

PERSONAL PROTECTIVE EQUIPMENT

Personal Protective Equipment: Eyes/Face
Wear chemical goggles; face shield (if splashing is possible).

Personal Protective Equipment: Skin
Use impervious gloves. Use of an impervious apron and boots is recommended.

Personal Protective Equipment: Respiratory
If ventilation is not sufficient to effectively prevent buildup of vapor or mist, appropriate NIOSH respiratory protection must be provided.

Personal Protective Equipment: General
Use good hygiene practices when handling this material, including changing and laundering work clothes after use. Discard contaminated shoes and leather goods.

*** Section 9 - Physical & Chemical Properties ***

Appearance:	Dark brown	**Odor:**	Typical
Physical State:	Liquid	**pH:**	<1 at approximately 100 g/l at approximately25°C (77°F)
Vapor Pressure:	23 hPa at 20°C (68°F) (Based on water)	**Vapor Density:**	> 1 (air = 1)
Boiling Point:	100°C (212°F) at 1.013 hPa (approximately)	**Melting Point:**	Not determined
Solubility (H2O):	> 300 g/l at approximately 25°C (77°F)	**Specific Gravity:**	1.1 at 77°F (25°C)
Evaporation Rate:	Slower than ethyl ether	**Viscosity:**	10 - 30 mPas at approximately 25°C (77°F)

*** Section 10 - Chemical Stability & Reactivity Information ***

Chemical Stability
This is a stable material.

Chemical Stability: Conditions to Avoid
Keep away from heat, sparks, or open flame. Avoid strong oxidizing agents.

Incompatibility
May react with oxidizing agents, bases and other acid reactive materials. This product contains a component that reacts with water.

Hazardous Decomposition
Sulfur oxides, carbon monoxide, carbon dioxide and other hydrocarbon fragments.

Hazardous Polymerization
Will not occur.

*** Section 11 - Toxicological Information ***

Acute and Chronic Toxicity

A: General Product Information
May cause severe irritation or burns to the eyes, skin, gastrointestinal tract, and respiratory system.

B: Component Analysis - LD50/LC50

p-Toluenesulfonic acid (104-15-4)
Oral LD50 Rat: 2480 mg/kg

Sulfuric acid (7664-93-9)
Inhalation LC50 Rat: 510 mg/m3/2H; Inhalation LC50 Mouse: 320 mg/m3/2H; Oral LD50 Rat: 2140 mg/kg

Carcinogenicity

A: General Product Information
Suspect cancer hazard. Contains sulfuric acid which may cause cancer.

B: Component Carcinogenicity

Sulfuric acid (7664-93-9)

ACGIH: A2 - Suspected Human Carcinogen (contained in strong inorganic acid mists)
IARC: Monograph 54, 1992 (Group 1 (carcinogenic to humans))

*** Section 12 - Ecological Information ***

Ecotoxicity

A: General Product Information

No additional information available.

B: Component Analysis - Ecotoxicity - Aquatic Toxicity

No ecotoxicity data are available for this product's components.

Environmental Fate

No additional information available.

*** Section 13 - Disposal Considerations ***

US EPA Waste Number & Descriptions

A: General Product Information

If discarded, this product is considered a RCRA corrosive waste, D003.
Wastes must be tested using methods described in 40 CFR Part 261 to determine if it meets applicable definitions of hazardous wastes.

B: Component Waste Numbers

No EPA Waste Numbers are applicable for this product's components.

Disposal Instructions

Dispose of waste material according to Local, State, Federal, and Provincial Environmental Regulations.

*** Section 14 - Transportation Information ***

US DOT Information

Shipping Name: Alkyl sulfonic acids, liquid
UN/NA #: UN2586 **Hazard Class:** 8 **Packing Group:** III

TDG Information

Shipping Name: Alkylsulfonic acids, liquid
UN/NA #: UN2586 **Hazard Class:** 8 **Packing Group:** III

IATA Information

Shipping Name: Alkylsulphonic acids, liquid
UN #: UN2586 **Hazard Class:** 8 **Packing Group:** III

ICAO Information

Shipping Name: Alkylsulphonic acids, liquid
UN #: UN2586 **Hazard Class:** 8 **Packing Group:** III

IMDG Information

Shipping Name: Alkylsulphonic acids, liquid
UN #: UN2586 **Hazard Class:** 8 **Packing Group:** III

*** Section 15 - Regulatory Information ***

US Federal Regulations

A: General Product Information

No additional information available.

Material Safety Data Sheet

Material Name: RCT Activator FA001 **ID: FA001**

B: Component Analysis

This material contains one or more of the following chemicals required to be identified under SARA Section 302 (40 CFR 355 Appendix A), SARA Section 313 (40 CFR 372.65) and/or CERCLA (40 CFR 302.4).

Sulfuric acid (7664-93-9)

SARA 302: 1000 lb TPQ
SARA 313: 1.0 % de minimis concentration (acid aerosols including mists, vapors, gas, fog, and other airborne forms of any particle size)
CERCLA: 1000 lb final RQ; 454 kg final RQ

Acute Health: Yes **Chronic Health:** Yes **Fire:** No **Pressure:** No **Reactive:** Yes

State Regulations

A: General Product Information

Other state regulations may apply. Check individual state requirements.

B: Component Analysis - State

The following components appear on one or more of the following state hazardous substances lists:

Component	CAS	CA	MA	MN	NJ	PA	RI
p-Toluenesulfonic acid	104-15-4	No	Yes	No	No	Yes	No
Sulfuric acid	7664-93-9	Yes	Yes	Yes	Yes	Yes	Yes

Canadian WHMIS Information

A: General Product Information

This product has been classified in accordance with the hazard criteria of the Controlled Products Regulations (CPR) and the MSDS contains all information required by the CPR.

B: Component Analysis - WHMIS IDL

The following components are identified under the Canadian Hazardous Products Act Ingredient Disclosure List:

Component	CAS #	Minimum Concentration
Sulfuric acid	7664-93-9	1 % (English Item 1485, French Item 138)

WHMIS Classification: Class E, D2A

Additional Regulatory Information

A: General Product Information

Components of this product have been checked against the non-confidential TSCA inventory by CAS Registry Number. Components not identified on this non-confidential inventory are exempt from listing (i.e. as polymers) or are listed on the confidential inventory as declared by the supplier.

B: Component Analysis - Inventory

Component	CAS #	TSCA	DSL	EINECS	AUST	PHIL	MITI	KOREA	CHINA
p-Toluenesulfonic acid	104-15-4	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Sulfuric acid	7664-93-9	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

* * * Section 16 - Other Information * * *

Other Information

User assumes all risks incident to the use of this product. To the best of our knowledge, the information contained herein is accurate. However, Extrude Hone Corporation assumes no liability whatsoever for the accuracy or completeness of the information contained herein. No representations or warranties, either expressed or implied, or merchantability, fitness for a particular purpose or of any other nature are made hereunder with respect to information or the product to which information refers. Extrude Hone assumes no liability for any loss, damage, injury of any kind which may result from or arise out of the use or reliance on the information by any person. The data contained on this sheet apply to the material as supplied to the user.

Page 5 of 6 Issue Date: 10/04/04 Revision: 1.0000 Print Date: 10/13/2004

Material Safety Data Sheet

Material Name: RCT Activator FA001 **ID: FA001**

Key/Legend

ACGIH = American Conference of Governmental Industrial Hygienists; CAS = Chemical Abstracts Service; CERCLA = Comprehensive Environmental Response, Compensation, and Liability Act; CFR = Code of Federal Regulations; CPR = Controlled Products Regulations; DOT = Department of Transportation; DSL = Domestic Substances List; EINECS = European Inventory of Existing Commercial Chemical Substances; EPA = Environmental Protection Agency; IARC = International Agency for Research on Cancer; IATA = International Air Transport Association; mg/Kg = milligrams per Kilogram; mg/L = milligrams per Liter; mg/m3 = milligrams per Cubic Meter; MSHA = Mine Safety and Health Administration; NA = Not Applicable or Not Available; NIOSH = National Institute for Occupational Safety and Health; NJTSR = New Jersey Trade Secret Registry; NTP = National Toxicology Program; OSHA = Occupational Safety and Health Administration; SARA = Superfund Amendments and Reauthorization Act; TDG = Transport Dangerous Goods; TSCA = Toxic Substances Control Act; WHMIS = Workplace Hazardous Materials Information System.

Contact: MSDS Information
Contact Phone: 724-863-5900

This is the end of MSDS # FA001

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EXTRUDEHONE® PROMETAL® RAPID CASTING TECHNOLOGIES RCT

MATERIAL SAFETY DATA SHEET

RCT Binder FB001 MSDS Prepared: 12/18/03

SECTION 1: IDENTIFICATION OF THE PRODUCT AND COMPANY

Product Identity: RCT Binder FB001

Company: Extrude Hone Corporation
1 Industry Blvd
PO Box 1000
Irwin, PA 15642
(724) 863-5900
(724) 862-8759 (fax)

:

SECTION 2: COMPOSITION / INFORMATION ON INGREDIENTS

Contains:	CAS Number	% (by weight)
Furfuryl Alcohol	98-00-0	75.0 - 90.0
Bisphenol A	80-05-7	5.0 - 15.0
Resorcinol	108-46-3	<= 10.0
Formaldehyde	50-00-0	0.2 - 0.4

SECTION 3: HAZARDS IDENTIFICATION

Potential Health Effects

Eye

Can cause permanent eye injury. Symptoms include stinging, tearing, redness, and swelling of eyes. Can injure the cornea and cause blindness.

Skin

Can cause permanent skin damage. Symptoms may include redness, burning, swelling of skin, burns, and other skin damage. Passage of this material into the body through the skin is possible, and may add to toxic effects from breathing or swallowing.

1

Swallowing

Swallowing this material may be harmful.

Inhalation

It is possible to breathe this material under certain conditions of handling and use (for example, during heating, spraying, or stirring). Breathing this material may be harmful. Symptoms usually occur at air concentrations higher than the recommended exposure limits (see Section 8).

Symptoms of Exposure

Signs and symptoms of exposure to this material through breathing, swallowing, and/or passage of the material through the skin may include: stomach or intestinal upset (nausea, vomiting, diarrhea), irritation (nose, throat, airways), central nervous system excitation (giddiness, liveliness, light-headed feeling) followed by central nervous system depression (dizziness, drowsiness, weakness, fatigue, nausea, headache, unconsciousness), and other central nervous system effects , low body temperature, chest pain effects on heart rate, effects on breathing rate, difficult breathing, and death. May cause methemaglobinemia, a blood abnormality that may cause headache, difficulty breathing, lightheadedness, weakness, confusion, rapid heart rate and cyanosis (lack of oxygen in the tissues causing blue-colored skin and nails).

Target Organ Effects

Overexposure to this material (or its components) has been suggested as a cause of the following effects in laboratory animals: thyroid effects, nasal damage, kidney damage, liver damage, brain damage.

Developmental Information

There are no data available for assessing risk to the fetus from maternal exposure to this material.

Cancer Information

Inhalation of formaldehyde has been shown to cause nasal tumors in rats, and ingestion of formaldehyde in drinking water has been shown to cause leukemia and gastrointestinal tract tumors in rats. Epidemiological studies has not clearly associated exposure to formaldehyde with cancer in man. Formaldehyde is listed as a carcinogen by the International agency for Research on Cancer (IARC), and the National Toxicology Program (NTP).

Formaldehyde (50-00-0)	IARC Group 2A (probably carcenogenic to humans)
	NTP Reasonably Anticipated to be a Carcinogen

Other Health Effects

No data

Primary Route(s) of Entry

Inhalation, Skin absorption, Skin contact, Eye contact, Ingestion

2

SECTION 4: FIRST AID MEASURES

Eyes

If material gets into the eyes, immediately flush eyes gently with water for at least 15 minutes while holding eyelids open. If symptoms develop as a result of vapor exposure, immediately move individual away from exposure and into fresh air before flushing as recommended above. Seek immediate medical attention.

Skin

Immediately flush skin with water for at least 15 minutes while removing contaminated clothing and shoes. Seek immediate medical attention. Wash exposed area with soap and water. If symptoms persist, seek medical attention. Wash clothing before reuse and decontaminate or discard contaminated shoes.

Swallowing

Seek immediate medical attention. If individual is drowsy or unconscious, do not give anything by mouth; place individual on the left side with the head down. Contact a physician, medical facility, or poison control center for advice about whether to induce vomiting. If possible, do not leave individual unattended.

Inhalation

If symptoms develop, immediately move individual away from exposure and into fresh air. Seek immediate medical attention; keep person warm and quiet. If person is not breathing, begin artificial respiration. If breathing is difficult, administer oxygen.

SECTION 5: FIRE FIGHTING MEASURES

Flash Point

172 F 78 C

Explosive Limit

(for component) Lower 1.4% Upper 16.3%

Autoignition Temperature

No data

Hazardous Products of Combustion

May form: aldehydes, carbon dioxide and carbon monoxide, nitrogen compounds, phenols, various hydrocarbons.

Fire and Explosion Hazards

Never use welding or cutting torch on or near drum (even empty) because product (even just residue) can ignite explosively.

Extinguishing Media

Foam, alcohol foam, water fog, carbon dioxide, dry chemical.

Fire Fighting Instructions

Wear a self-contained breathing apparatus with a full facepiece operated in the positive pressure demand mode with appropriate turn-out gear and chemical resistant protective equipment. Refer to the personal protective equipment section of this MSDS.

NFPA Rating

Health - 3, Flammability - 2, Reactivity - 1

SECTION 6: ACCIDENTAL RELEASE MEASURES

Small Spill

Absorb liquid with vermiculite, floor absorbent or other absorbent material and transfer to hood. Eliminate all sources of ignition such as flares, flames (including pilot lights), and electrical sparks.

Large Spill

Eliminate all sources of ignition such as flares, flames (including pilot lights), and electrical sparks. Persons not wearing protective equipment should be excluded from the areas of spill until clean-up has been completed. Stop spill at source. Prevent from entering drains, sewers, streams or other bodies of water. Prevent from spreading. If run-off occurs, notify proper authorities as required. Pump or vacuum transfer spilled product to close containers for recovery. Absorb unrecoverable product. Transfer contaminated absorbent, soil, and other materials to containers for disposal.

SECTION 7: HANDLING AND STORAGE

Handling

Containers of this material may be hazardous when empty. Since emptied containers retain product residue (vapor, liquid, and/or solid), all hazard precautions given in the data sheet must be observed. All five-gallon pails and larger metal containers, including tank cars and tank trucks, should be grounded and/or bonded when material is transferred. Do not add peroxides or acids with binder in absence of sand. This product is a component of a foundry binder system. Thermal decomposition during pouring, cooling and shakeout will produce numerous airborne contaminants, including carbon monoxide, aldehydes, phenols, oxygenated compounds, isocyanates, hydrocarbons, nitrogen compounds and particulates.

Storage

Do not store near extreme heat, open flame, or sources of ignition.

SECTION 8: EXPOSURE CONTROLS / PERSONAL PROTECTION

Eye Protection

Chemical splash goggles and face shield (8" min.) in compliance with OSHA regulations are advised; however, OSHA regulations also permit other types of safety glasses. (Consult your industrial hygienist.)

Skin Protection

Wear resistant gloves such as: polyethylene. To prevent repeated or prolonged skin contact, wear impervious clothing and boots.

Respiratory Protection

If workplace exposure limits(s) of product or any component is exceeded (see exposure guidelines), a NIOSH/MSHA approved air supplied respirator is advised in absence of proper environmental control. OSHA regulations also permit other NIOSH/MSHA respirators (negative pressure type) under specified conditions (see your industrial hygienist). Engineering or administrative controls should be implemented to reduce exposure.

Engineering Controls

Provide sufficient mechanical (general and/or local exhaust) ventilation to maintain exposure below TLV(s).

Exposure Guidelines

Furfuryl Alcohol (98-00-0)

OSHA PEL 50.00 ppm - TWA
OSHA VPEL 10.00 ppm - TWA (skin)
OSHA VPEL 15.00 ppm - STEL (skin)
ACGIH TLV 10.00 ppm - TWA (skin)
ACGIH TLV 15.00 ppm - STEL (skin)

Bisphenol A (80-5-7)

No exposure limits established

Resorcinol (108-46-3)

OSHA VPEL 10.00 ppm - TWA
OSHA VPEL 20.00 ppm - STEL
ACGIH TLV 10.00 ppm - TWA
ACGIH TLV 20.00 ppm - STEL

Formaldehyde (50-00-0)

OSHA PEL 0.75 ppm - TWA
OSHA PEL 2.00 ppm – STEL
OSHA PEL 0.5 ppm Action Level (Irritant and potential cancer hazard - see 29 CFR 1910.1048)
OSHA VPEL 10 ppm (30 min, unless specified in 1910.1048) - STEL
ACGIH TLV 0.30 ppm – ceiling

SECTION 9: PHYSICAL AND CHEMICAL PROPERTIES

Boiling Point

(range) 338 F 170 C @ 760 mm Hg

Vapor Pressure

(for component) 0.610 mm Hg

5

Specific Vapor Density
No data

Specific Gravity
1.150 @ 77.00 F

Liquid Density
9.580 lbs/gal @ 77.00F
1.150 kg/l @ 25.00 C

Percent Volatiles
No data

Evaporation Rate
Slower than ethyl ether

Appearance
Clear

State
Liquid

Physical Form
Homogeneous solution

Color
No data

Odor
No data

pH
No data

SECTION 10: STABILITY AND REACTIVITY

Hazardous Polymerization
Acid contamination can cause violent exothermic polymerization.

Hazardous Decomposition
May form: aldehydes, carbon dioxide and carbon monoxide, nitrogen compounds, phenols, various hydrocarbons.

Chemical Stability
Stable

Incompatibility
Avoid contact with: strong acids, strong alkalies, strong mineral acids.

6

SECTION 11: TOXICOLOGICAL INFORMATION

No data

SECTION 12: ECOLOGICAL INFORMATION

No data

SECTION 13. DISPOSAL CONSIDERATION

Waste Management Information
Wastes must be tested using methods described in 40 CFR 261 to determine if it meets applicable requirements of hazardous wastes.

SECTION 14. TRANSPORT INFORMATION

DOT Information - 49 CFR 172.101
DOT Description:
Furfuryl alcohol, mixture 6.1, UN2874, III

Container / Mode:
55 gallon drum / truck package

NOS component:
none

Other Transportation Information
The DOT Transport Information may vary with the container and mode of shipment.

SECTION 15. REGULATORY INFORMATION

US Federal Regulations
TSCA (Toxic Substances Control Act) Status
TSCA (United States) The intentional ingredients of this product are listed.

CERCLA RQ - 40 CFR 302.4 (a)
Component: Resorcinol
RQ: 5000 lbs
Component: formaldehyde
RQ: 100 lbs

CERCLA RQ - 40 CFR 302.4.(b)
Materials without a "listed" RQ may be reportable as an "unlisted hazardous substance". See 40 CFR 302.5 (b).

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SARA 302 Components – 40 CFR 355 Appendix A
Component: Formaldehyde
TPQ: 500 lbs

Section 311/312 Hazard Class - 40 CFR 370.2
Immediate, Delayed, Fire, Reactive

SARA 313 Components - 40 CFR 372.65

Section 313 Component(s)	CAS Number
Bisphenol A	80-05-7
Formaldehyde	50-00-0

OSHA Process Safety Management – 29 CFR 1910
PSM Component: Formaldehyde
TQ: 1000 lbs

EPA Accidental Release Prevention – 40 CFR 68
RMP Component: Formaldehyde (solution)
TQ: 15000 lbs

International Regulations
Inventory Status
AICS (Australia) The intentional ingredients of this product are listed.

DSL (Canada) The intentional ingredients of this product are listed.

ECL (South Korea) The intentional ingredients of this product are NOT listed.

State and Local Regulations
California Proposition 65
The following statement is made in order to comply with the California Safe Drinking Water and Toxic Enforcement Act of 1986: This product contains a substance known to the state of California to cause cancer.

New Jersey RTK Label Information
Furfuryl alcohol (98-00-0)
Bisphenol A (80-05-7)
Resorcinol (108-46-3)
Formaldehyde (50-00-0)

Pennsylvania RTK Label Information
Furfuryl alcohol (98-00-0)
Bisphenol A (80-05-7)
Resorcinol (108-46-3)

SECTION 16: OTHER INFORMATION

User assumes all risks incident to the use of this product. To the best of our knowledge, the information contained herein is accurate. However, Extrude Hone Corporation assumes no liability whatsoever for the accuracy or completeness of the information contained herein. No representations or warranties, either expressed or implied, or merchantability, fitness for a particular purpose or of any other nature are made hereunder with respect to information or the product to which information refers. Extrude Hone assumes no liability for any loss, damage, injury of any kind which may result from or arise out of the use or reliance on the information by any person. The data contained on this sheet apply to the material as supplied to the user.

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EXTRUDEHONE® PROMETAL® RCT RAPID CASTING TECHNOLOGIES

MATERIAL SAFETY DATA SHEET

RCT Cleansing Solution FC001 MSDS Prepared: 3/15/04

SECTION 1: IDENTIFICATION OF THE PRODUCT AND COMPANY

Product Identity: RCT Cleansing Solution FC001

Company: Extrude Hone Corporation
1 Industry Blvd
PO Box 1000
Irwin, PA 15642
(724) 863-5900
(724) 862-8759 (fax)

:

SECTION 2: COMPOSITION / INFORMATION ON INGREDIENTS

Contains:	CAS Number	% (by weight)
Ethanol	64-17-5	80.0 - 90.0
Isopropanol	67-63-0	0.0 - 10.0
Methanol	67-56-1	0.0 – 5.0
Methyl Isobutyl Ketone	108-10-1	0.0 – 2.0

SECTION 3: HAZARDS IDENTIFICATION

Fire Hazard
Highly flammable

Potential Health Effects

Eye
Irritating to eyes. Risk of serious damage to eyes.

Skin
Can be mildly irritating to skin.

1

Swallowing

Toxic: Danger of very serious irreversible effects if swallowed.

Inhalation

Irritating to nose and throat.

Symptoms of Exposure

Signs and symptoms of exposure to this material through breathing, swallowing, and/or passage of the material through the skin may include: headache, nausea, dizziness, drowsiness, incoordination, and/or confusion.

Primary Route(s) of Entry

Inhalation, Ingestion, Eye contact, Skin absorption, Skin contact

SECTION 4: FIRST AID MEASURES

Eyes

Flush with plenty of water for at least 15 minutes and get medical attention.

Skin

Immediately remove contaminated clothing. Wash thoroughly with soap and water. Wash contaminated clothing before reuse.

Swallowing

Induce vomiting promptly using physician's instructions or by having patient stick finger down throat. After vomiting has been induced, give two teaspoonsful of baking soda in a glass of water. CALL A PHYSICIAN. Never give anything by mouth to an unconscious person. Have patient lie down and keep warm. Cover eyes to exclude light.

Inhalation

After high vapor exposure, remove to fresh air. If breathing is difficult, give oxygen. If breathing has stopped, give artificial respiration.

SECTION 5: FIRE FIGHTING MEASURES

Flash Point

40 F 4 C

Explosive Limit

Lower 4.2%

Autoignition Temperature

700 F 371 C

Hazardous Products of Combustion

carbon monoxide and carbon dioxide

Fire and Explosion Hazards

Highly flammable. Vapors can cause flash fire.

Extinguishing Media

NFPA Class B extinguishers (carbon dioxide or foam) for Class I B liquid fires.

Fire Fighting Instructions

Water spray may be ineffective on fire but can protect fire-fighters and cool closed containers.Use fog nozzles if water is used. Do not enter confined fire-space without full bunker gear (helmet with face shield, bunker coats, gloves and rubber boots). Use NIOSH-approved positive pressure self-contained breathing apparatus.

Unusual Explosion and Fire Procedures

Keep container tightly closed. Isolate from oxidizers, heat, sparks, electric equipment and open flame. Closed containers may explode if exposed to extreme heat. Applying to hot surfaces requires special precautions. Empty container very hazardous. Continue all label precautions.

NFPA Rating

Health - 1, Flammability - 3, Reactivity - 0

SECTION 6: ACCIDENTAL RELEASE MEASURES

Containment Techniques

Stop spill at source. Dike area and contain.

Clean-up Procedures

Clean up remainder with absorbent materials. Mop up & dispose of. Persons without proper protection should be kept from area until cleaned up.

SECTION 7: HANDLING AND STORAGE

Handling

Isolate from oxidizers, heat, sparks, electric equipment & open flame. Use only with adequate ventilation. Avoid breathing of vapor or spray mist. Avoid contact with skin & eyes. Wear OSHA standard goggles or face shield. Consult safety equipment supplier. Wear gloves, apron & footwear impervious to this material. Wash clothing before reuse. Avoid free-fall of liquid. Ground containers when transferring. Do not flame cut, saw, drill, braze, or weld. Empty container is very hazardous. Continue all label precautions.

Storage

Do not store above 120 F (49 C). Store large amounts in structures made for OSHA Class I B liquids. Keep container tightly closed and upright when not in use to prevent leakage.

SECTION 8: EXPOSURE CONTROLS / PERSONAL PROTECTION

Exposure Controls

Ventilate to keep vapors of this material below 285 ppm. If over TLV, in accordance with 29 CFR 1910.134, use NIOSH approved positive-pressure self-contained breathing apparatus. Consult safety equipment supplier. Use explosion-proof equipment.

Ventilation

Local exhaust:	Necessary
Mechanical (general):	Acceptable
Special:	none
Other:	none

Personal Protections

Wear OSHA standard goggles or face shield. Consult safety equipment supplier. Wear gloves, apron and footwear impervious to this material. Wash clothing before reuse.

Work and Hygienic Practices

Provide readily accessible eye wash stations and safety showers. Wash at end of each workshift and before eating, smoking, or using the toilet. Promptly remove clothing that becomes contaminated. Destroy contaminated leather articles. Launder or discard contaminated clothing.

Exposure Guidelines

Ethanol (64-17-5)
OSHA PEL 1000.00 ppm - TWA
ACGIH TLV 1000.00 ppm - TWA

Isopropanol (67-63-0)
OSHA PEL 400.00 ppm - TWA
OSHA VPEL 400.00 ppm - STEL
ACGIH TLV 200.00 ppm - TWA
ACGIH TLV 400.00 ppm - STEL

Methanol (67-56-1)
OSHA PEL 200.00 ppm - TWA
OSHA VPEL 250.00 ppm - STEL
ACGIH TLV 200.00 ppm – TWA
ACGIH TLV 250.00 ppm - STEL
EPA hazardous air pollutant

Methyl Isobutyl Ketone (108-10-1)
OSHA PEL 100.00 ppm - TWA
OSHA VPEL 75.00 ppm - STEL
ACGIH TLV 50.00 ppm - TWA
ACGIH TLV 75.00 ppm - STEL
EPA hazardous air pollutant

SECTION 9: PHYSICAL AND CHEMICAL PROPERTIES

Boiling Range
(for components) 147 F (63 C) 171 F (77 C) 243 F (117 C) @ 760 mm Hg

Vapor Pressure
46.5 mm Hg

Specific Vapor Density
1.6 (air = 1)

Specific Gravity
0.794 @ 77.00 F

Liquid Density
6.616 lbs/gal @ 77.00F
0.794 kg/l @ 25.00 C

Evaporation Rate
2.4 (n-butyl acetate = 1)

Appearance
Clear

State
Liquid

Odor
Ketone

pH
No data

SECTION 10: STABILITY AND REACTIVITY

Stability
Stable

Conditions to Avoid
Isolate from oxidizers, heat, sparks, electric equipment and open flame.

Materials to Avoid
Isolate from strong oxidizers such as permanganated, chromates, and peroxides.

Hazardous Polymerization
Will not occur.

Hazardous Decomposition Products
Carbon monoxide, carbon dioxide from burning.

SECTION 11: TOXICOLOGICAL INFORMATION

Acute Hazards

Eye and Skin Contact

Primary irritation to skin, defatting, dermatitis. Primary irritation to eyes, redness, tearing, blurred vision. Liquid can cause eye irritation. Wash thoroughly after handling.

Inhalation

Anesthetic. Irritates respiratory tract. Acute overexposure can cause serious nervous system depression. Vapor harmful. Breathing vapor can cause irritation. Acute overexposure can cause damage to kidneys, blood, nerves, liver, and lungs. Repeated overexposure over TLV can cause blindness.

Swallowing

Can be fatal or cause blindness if swallowed. Cannot be made non-poisonous. POISON. Can cause irreversible nervous system damage and death. Harmful or fatal if swallowed. Swallowing can cause abdominal irritation, nausea, vomiting and diarrhea.

Subchronic Hazards / Conditions Aggravated

Conditions Aggravated

Chronic overexposure can cause damage to kidneys, blood, nerves, liver and lungs. Persons with severe skin, liver or kidney problems should avoid use.

Chronic Hazards

Cancer, Reproductive and Other Chronic Hazards

Absorption through skin may be harmful. Studies with laboratory animals indicate this product can cause damage to fetus.

SECTION 12: ECOLOGICAL INFORMATION

Mobility

This material is a mobile liquid.

Degradability

This product is completely biodegradable.

Accumulation

This product does not accumulate or biomagnify in the environment.

6

SECTION 13. DISPOSAL CONSIDERATION

Waste Management Information
Recycle / dispose of observing national, regional, state, provincial and local health, safety, and pollution laws.

SECTION 14. TRANSPORT INFORMATION

DOT Shipping Name
Alcohols, N.O.S. (Ethanol, Methanol), 3, UN1987, PG-II
Drum Label: Flammable Liquid
Additional Info: Emergency Response Guidebook Number: 127

IATA / ICAO
Alcohols, N.O.S. (Ethanol, Methanol), 3, UN1987, PG-II,
Label: Flammable Liquid
Additional Info: Poison

IMO / IMDG
Alcohols, N.O.S. (Ethanol, Methanol), 3, UN1987, PG-II,
Label: Flammable Liquid
Additional Info: Poison

SECTION 15. REGULATORY INFORMATION

US Federal Regulations
TSCA (Toxic Substances Control Act) Status
TSCA (United States) The intentional ingredients of this product are listed.

Section 311/312 Hazard Class - 40 CFR 370.2
Acute health, Fire

SARA 313 Components - 40 CFR 372.65

Section 313 Component(s)	CAS Number
Ethanol	64-17-5
Isopropanol	67-63-0
Methanol	67-56-1
Methyl Isobutyl Ketone	108-10-1

International Regulations
Inventory Status
Listed on the chemical inventories of the following countries: Australia, Cancada, Europe (EINECS), Japan, Korea, United Kingdom

SECTION 16: OTHER INFORMATION

User assumes all risks incident to the use of this product. To the best of our knowledge, the information contained herein is accurate. However, Extrude Hone Corporation assumes no liability whatsoever for the accuracy or completeness of the information contained herein. No representations or warranties, either expressed or implied, or merchantability, fitness for a particular purpose or of any other nature are made hereunder with respect to information or the product to which information refers. Extrude Hone assumes no liability for any loss, damage, injury of any kind which may result from or arise out of the use or reliance on the information by any person. The data contained on this sheet apply to the material as supplied to the user.

EXTRUDEHONE® PROMETAL® RCT RAPID CASTING TECHNOLOGIES

MATERIAL SAFETY DATA SHEET

RCT Permeable Casting Media S-001 MSDS Prepared: 11/04/04

SECTION 1: IDENTIFICATION OF THE PRODUCT AND COMPANY

Product Identity: RCT Permeable Casting Media S-001

Company: Extrude Hone Corporation
1 Industry Blvd
PO Box 1000
Irwin, PA 15642
(724) 863-5900
(724) 862-8759 (fax)

24-hour Emergency Contact: CHEMTREC 1-800 424-9300

SECTION 2: COMPOSITION / INFORMATION ON INGREDIENTS

Contains:	CAS Number	% (by weight)
Crystalline Silica (quartz)	14808-60-7	99.7 - 90.9
Aluminum Oxide	1344-28-1	< 1
Iron Oxide	1309-37-1	< 1
Titanium Oxide	13463-67-7	< 1

SECTION 3: HAZARDS IDENTIFICATION

Light tan to white particulate material. It is not flammable, combustible, or explosive. It can cause irritation to the eyes.

Potential Health Effects

Inhalation

Silicosis – Respirable crystalline silica (quartz) can cause silicosis, a fibrosis (scarring) of the lungs. Silicosis may be progressive; it may lead to disability and death.

1

Cancer – Crystalline silica (quartz) inhaled from occupational sources is classified as carcinogenic to humans.
Autoimmune diseases – There are some studies that show excess numbers of cases of scleroderma and other connective tissue disorders in workers exposed to respirable crystalline silica.
Tuberculosis – Silicosis increases the risk of tuberculosis.
Nephrotoxicity – There are some studies that show an increased incidence of chronic kidney disease and end-stage renal disease in workers exposed to respirable crystalline silica.

Eye
Crystalline silica (quartz) may cause abrasion of the cornea.

Skin contact
Not applicable

Ingestion
Not applicable

Chronic effects
The adverse health effects – silicosis, cancer, autoimmune diseases, tuberculosis, and nephrotoxicity – are chronic effects.

Signs and symptoms of exposure
Generally, there are no signs or symptoms of exposure to crystalline silica (quartz).

Medical conditions generally aggravated by exposure
The condition of individuals with lung disease (e.g. bronchitis, emphysema, chronic obstructive pulmonary disease) can be aggravated by exposure.

See section 11, Toxological Information, for additional detail on potential adverse health effects.

SECTION 4: FIRST AID MEASURES

Inhalation
No specific first-aid is necessary since the adverse health effects associated with exposure to crystalline silica (quartz) result from chronic exposures. If there is a gross inhalation of crystalline silica (quartz), remove the person immediately to fresh air, give artificial respiration as needed, seek medical attention as needed.

Eye contact
Wash immediately with water. If irritation persists, seek medical attention.

Skin contact
Not applicable.

Ingestion
If large amounts are ingested, seek medical attention.

SECTION 5: FIRE FIGHTING MEASURES

Crystalline silica (quartz) is not flammable, combustible, or explosive.

Flash Point: None

Explosive Limit: Not applicable

Autoignition Temperature: None

Hazardous Products of Combustion: None

Fire and Explosion Hazards: None

Extinguishing Media
Compatible with all media; use the medium appropriate to the surrounding fire.

Special Fire Fighting Procedures
None with respect to this product.

NFPA Rating
Health - 0, Flammability - 0, Reactivity - 0

SECTION 6: ACCIDENTAL RELEASE MEASURES

Wear appropriate personal protective equipment as described in Section 8 of this document.

Spills
Do not dry sweep. Use dustless methods (High-Efficiency Particulate Air (HEPA) vacuum or thoroughly wetting down the silica). Place the silica in a covered container appropriate for disposal. Dispose of the silica according to federal, state, and local regulations.

Waste disposal method
See Section 13.

SECTION 7: HANDLING AND STORAGE

Handling and Use
Do not breath dust. Use adequate ventilation and dust collection. Keep airborne dust concentrations below PEL. Do not rely on your sight to determine if there is dust in the air. Silica may be in the air without a visible dust cloud. If dust cannot be kept below permissible limits, wear a respirator approved for silica dust when using, handling, storing, or disposing of this product or bag. Practice good housekeeping. Do not permit dust to collect on walls, floors, sills, ledges, machinery, or equipment. Maintain, clean, and fit test respirators in accordance with OSHA regulations. Maintain and test

ventilation and dust collection equipment. Wash or vacuum clothing that has become dusty. See also control measures in Section 8.

Storage

Avoid breakage of bagged material or spills of bulk material. See control measures in Section 8.

SECTION 8: EXPOSURE CONTROLS / PERSONAL PROTECTION

Ventilation

Local exhaust – Use sufficient local exhaust to reduce the level of respirable crystalline silica to below the PEL. See ACGIH "Industrial Ventilation, A Manual of Recommended Practice"

Exposure Limits

OSHA-PEL	0.1 mg/m^3 (silica, crystalline quartz, respirable dust) See 29 CFR 1910
ACGIH-TLV	0.05 mg/m^3 (respirable fraction)
NIOSH-REL	0.05 mg/m^3

Respiratory Protection

The following table (NIOSH recommendations for silica (crystalline respirable dust) in air) specifies the types of respirators which may provide respiratory protection for crystalline silica.

Up to 0.5 mg/m^3	Air purifying respiratory with high-efficiency particulate filter(s)
Up to 1.25 mg/m^3	Powered air-purifying respirator with high-efficiency particulate filter; or supplied air respirator (SAR) operated in continuous-flow mode
Up to 2.5 mg/m^3	Full-facepiece air-purifying respirator with high-efficiency particulate filter(s); or powered air-purifying respirator with tight-fitting facepiece and high-efficiency particulate filter
Up to 25 mg/m^3	Positive pressure SAR.
Planned or emergency entry into unknown concentrations	Positive pressure, full-facepiece self-contained breathing apparatus (SCBA); or positive pressure, full facepiece SAR with an auxiliary positive pressure SCBA.
Escape	Full-facepiece respirator with high-efficiency particulate filter(s); or escape-type SCBA.

Use only NIOSH-approved or MSHA-approved equipment (29 CFR 1910.134, 42 CFR 84)

Personal Protections

Gloves

Recommended in situations where abrasion may occur.

Eye

Goggles recommended where airborne dust is produced.

Other

Protective clothing as appropriate for the work environment. Dusty clothing should be laundered before it is reused. Do not take dusty clothing home.

SECTION 9: PHYSICAL AND CHEMICAL PROPERTIES

Appearance	White or light tan particulate
Odor	None
Physical state	Granular solid
Boiling point	above 3500F
Melting point	above 2500F
Vapor pressure	none
Vapor density	none
Solubility in water	insoluble
Specific gravity	2.65

SECTION 10: STABILITY AND REACTIVITY

Stability:	Stable
Materials to Avoid:	Contact with strong oxidizing agents such as fluorine, chlorine trifluoride and oxygen diflouride may cause fires.
Hazardous Polymerization:	Will not occur.
Hazardous Decomposition Products:	Silica will dissolve in hydrofluoric acid and produce a corrosive gas – silicon tetraflouride.

SECTION 11: TOXICOLOGICAL INFORMATION

SILICOSIS

Silicosis (lung disease) can be caused by the inhalation and retention of respirable crystalline silica dust. Silicosis can exist in several forms, chronic (or ordinary), accelerated, or acute.

Chronic (or ordinary) silicosis is the most common form of silicosis and can occur after many years of exposure to levels above the occupational exposure limits for airborne respirable crystalline silica dust. It is further defined as either simple or complicated silicosis.

Simple silicosis is characterized by lung lesions (shown as radiographic opacities) less than 1 cm in diameter, primarily in the upper lung zones. Often, simple silicosis is not associated with symptoms, detectable changes in lung function or disability.

Simple silicosis may be progressive and may develop into complicated silicosis or progressive massive fibrosis (PMF). Complicated silicosis of PMF is characterized by lung lesions (shown as radiographic opacities) greater than 1 cm in diameter. Although there may be no symptoms associated with complicated silicosis or PMF, the symptoms, if present, are shortness of breath, wheezing, cough and sputum production. Complicated silicosis or PMF may be associated with decreased lung function and may be disabling. Advanced complicated silicosis or PMF may lead to death. Advanced complicated silicosis or PMF can result in heart disease secondary to the lung disease.

Accelerated silicosis can occur with exposure to high concentrations of respirable crystalline silica over a relatively short period; the lung lesions can appear within five years of the initial exposure. The progression can be rapid. Accelerated silicosis is similar to chronic or ordinary silicosis except that the lung lesions appear earlier and the progression is more rapid.

Acute silicosis can occur with exposure to very high concentrations of respirable crystalline silica over a very short time period, sometimes as short as a few months. The symptoms of acute silicosis include progressive shortness of breath, fever, cough and weight loss. Acute silicosis is fatal.

CANCER

The International Agency for Research on Cancer (IARC) concluded that there was "sufficient evidence in humans for the carcinogenicity of crystalline silica in the forms of quartz or cristobalite from occupational sources," and that there is "sufficient evidence in experimental animals for the carcinogenicity of quartz and cristobalite." The overall IARC evaluation was that "crystalline silica inhaled in the form of quartz or cristobalite from occupational sources is carcinogenic to humans (Group I)." The IARC evaluation noted that the "carcinogenicity was not detected in all industrial circumstances studies. Carcinogenicity may be dependent on inherent characteristics of the crystalline silica or on external factors affecting its biological activity or distribution of its polymorphs." For further information on the IARC evaluation see IARC Monographs on the Evaluation of Carcinogenic Risks to Humans, Volume 68, "Silica, Some Silicates…" (1997).

NTP – The National Toxicology Program, in its Ninth Annual Report on Carcinogens, classified "silica, crystalline (respirable)" as a known human carcinogen.

Many articles have been published on the carcinogenicity of crystalline silica. Examples include: "Crystalline Silica and Lung Cancer: The Problem of Conflicting Evidence," Indoor Built Environ., volume 8, pp. 121-126 (1998); "Exposure to Crystalline Silica and Risk of Lung Cancer; The Epidemiological Evidence," Thorax, volume 51, pp. 97-102 (1996); "Adverse Effects of Crystalline Silica Exposure," American Journal of Respiratory and Critical Care Medicine, volume 155, pp. 761-765 (1997).

SCLERODERMA

There is evidence that exposure to respirable crystalline silica or that the disease silicosis is associated with the increased incidence of scleroderma, an immune system disorder manifested by a fibrosis (scarring) of the lungs, skin, and other internal organs. Recently the American Thoracic Society noted that "there is persuasive evidence relating scleroderma to occupational silica exposures in setting where there is appreciable silicosis risk." The following may be consulted for additional information on silica, silicosis and scleroderma (also known as progressive systemic sclerosis): Occupational Lung Disorders, Third Edition, Chapter 12, entitled "Silicosis and Related Diseases," Parkes, W. Raymond (1994); "Adverse Effects of Crystalline Silica Exposure," American Journal of Respiratory and Critical Care Medicine, volume 155, pp. 761-765 (1997)

TUBERCULOSIS

Individuals with silicosis are at increased risk to develop pulmonary tuberculosis, if exposed to persons with tuberculosis. The following may be consulted for further information: Occupational Lung Disorders, Third Edition, Chapter 12, entitled "Silicosis and Related Diseases," Parkes, W. Raymond (1994); "Risk of Pulmonary Tuberculosis Relative to Silicosis and Exposure to Silica Dust in South African Gold Miners," Occup Environ Med., vol 55, pp. 496-502 (1998).

NEPHROTOXICITY

Several recent studies suggest that exposure to respirable crystalline silica or that the disease silicosis is associated with increased incidence of kidney disorders. The following may be consulted for additional information in silica, silicosis, and nephrotoxicity: Occupational Lung Disorders, Third Edition, Chapter 12, entitled "Silicosis and Related Diseases," Parkes, W. Raymond (1994); "Further Evidence of Human Silica Nephrotoxicity in Occupationally Exposed Workers," British Journal of Industrial Medicine, vol. 50, no. 10, pp. 907-912 (1993)); "Adverse Effects of Crystalline Silica Exposure," American Journal of Respiratory and Critical Care Medicine, volume 155, pp. 761-765 (1997).

SECTION 12: ECOLOGICAL INFORMATION

Crystalline silica is not known to be exotoxic.

SECTION 13. DISPOSAL CONSIDERATION

Crystalline silica may be landfilled; however, material should be covered to minimize generation of airborne dust.

Crystalline silica (quartz) is not classified as a hazardous waste under the Resource Conservation and Recovery Act or its regulations, 40 CFR 261.

Silica may become contaminated during industrial use. In the event of contamination, the user must determine the appropriate disposal method.

SECTION 14. TRANSPORT INFORMATION

Crystalline silica (quartz) is not a hazardous material for purposes of transportation under the U.S. Department of Transportation Table of Hazardous Materials, 49 CFR 172.101.

SECTION 15. REGULATORY INFORMATION

US Federal and State Regulations

TSCA (Toxic Substances Control Act)
Crystalline silica (quartz) appears on the EPA TSCA inventory under the CAS No. 14808-60-7.
RCRA (Resource Conservation and Recovery Act (40 CFR 261))
Crystalline silica (quartz) is not classified as a hazardous waste under the RCRA or its regulations, 40 CFR 261.

CERCLA (Comprehensive Environmental Response Compensation and Liability Act)
Crystalline silica (quartz) is not classified as a hazardous substance under regulations of CERCLA, 40 CFR 302.

Emergency Planning and Right to Know Act
Crystalline silica (quartz) is not an extremely hazardous substance under Section 302 and is not a toxic chemical subject to the requirements of Section 313.

Clean Air Act
Crystalline silica (quartz) does not contain any Class I or Class II ozone depleting substances.

FDA
Silica is included in the list of substances that may be included in coatings used in food contact surfaces, 21 CFR 175.300(b)(3)(xxvi).

NTP
Respirable crystalline silica is classified as a carcinogen.

OSHA Carcinogen
Crystalline silica (quartz) is not listed.

California Proposition 65
Crystalline silica (quartz) is classified as a substance known to the State of California to be a carcinogen.

Canada

Domestic Substances List

Silica, as a naturally occurring substance, is on the Canadian DSL.

WHMIS Classification: D2A

Other

EINECS No: 238-878-4

EEC Label (Risk/Safety Phrases): R48/20, R 40/20, S22, S38

IARC: Crystalline silica (quartz) is classified in IARC Group I.

National, state, provincial, or local emergency planning, community right-to-know or other laws, regulations or ordinances may be applicable. Consult applicable national, state, provincial, or local laws.

SECTION 16: OTHER INFORMATION

Hazardous Material Information System (HMIS)

Health	*
Flammability	0
Reactivity	0
Protective Equipment	E

* For information on health effects, see Sections 3 and 11 of this MSDS.

User assumes all risks incident to the use of this product. To the best of our knowledge, the information contained herein is accurate. However, Extrude Hone Corporation assumes no liability whatsoever for the accuracy or completeness of the information contained herein. No representations or warranties, either expressed or implied, or merchantability, fitness for a particular purpose or of any other nature are made hereunder with respect to information or the product to which information refers. Extrude Hone assumes no liability for any loss, damage, injury of any kind which may result from or arise out of the use or reliance on the information by any person. The data contained on this sheet apply to the material as supplied to the user.

APPENDIX C PRESENTATION DEFINING PROCESS AS PERFORMED

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-- *Patternless* and *Digital* --
Production of Molds and Cores for Sand Casting Applications

ProMetal Division
The Ex One Company

Presented to:

Rock Island Arsenal

Rock Island, IL

March 20, 2006

PROMETAL RCT RAPID CASTING TECHNOLOGIES

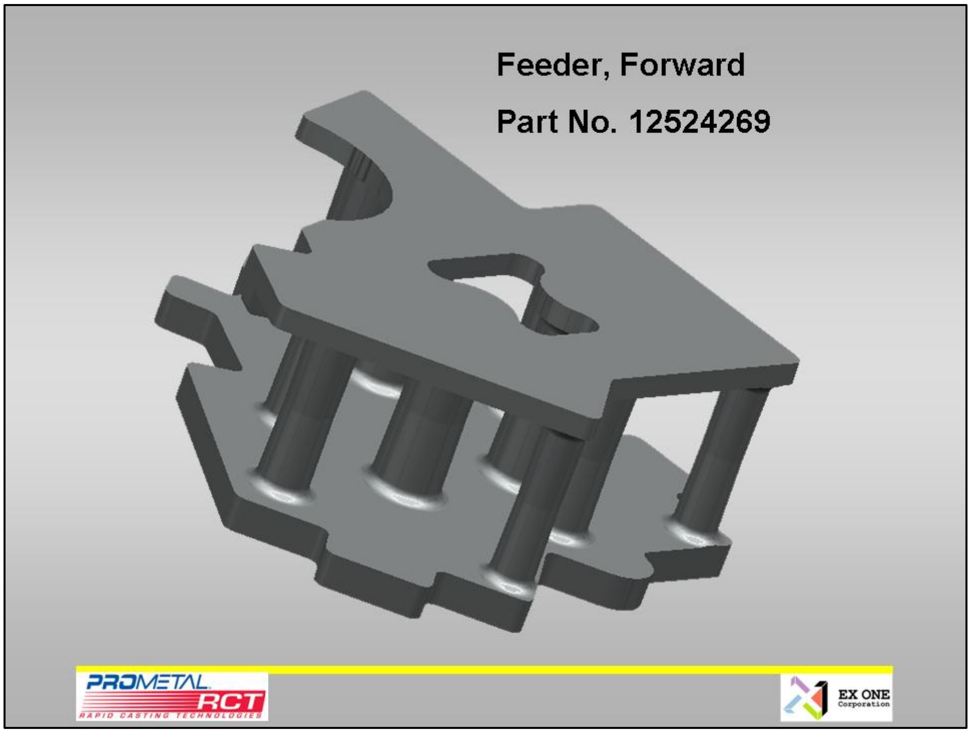
EX ONE Corporation

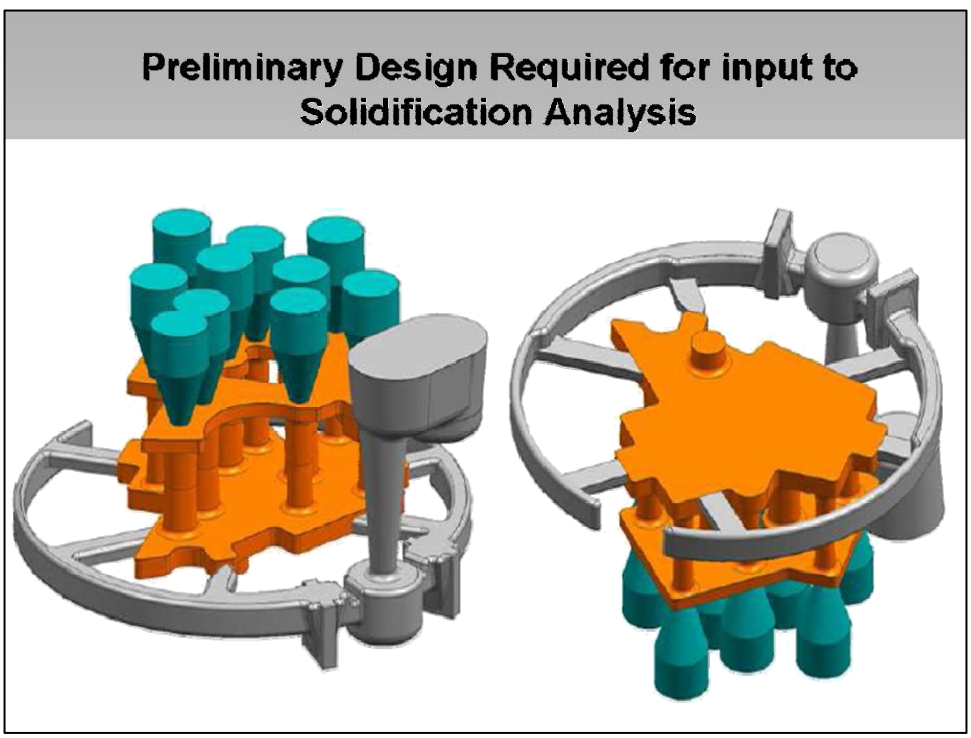
Process

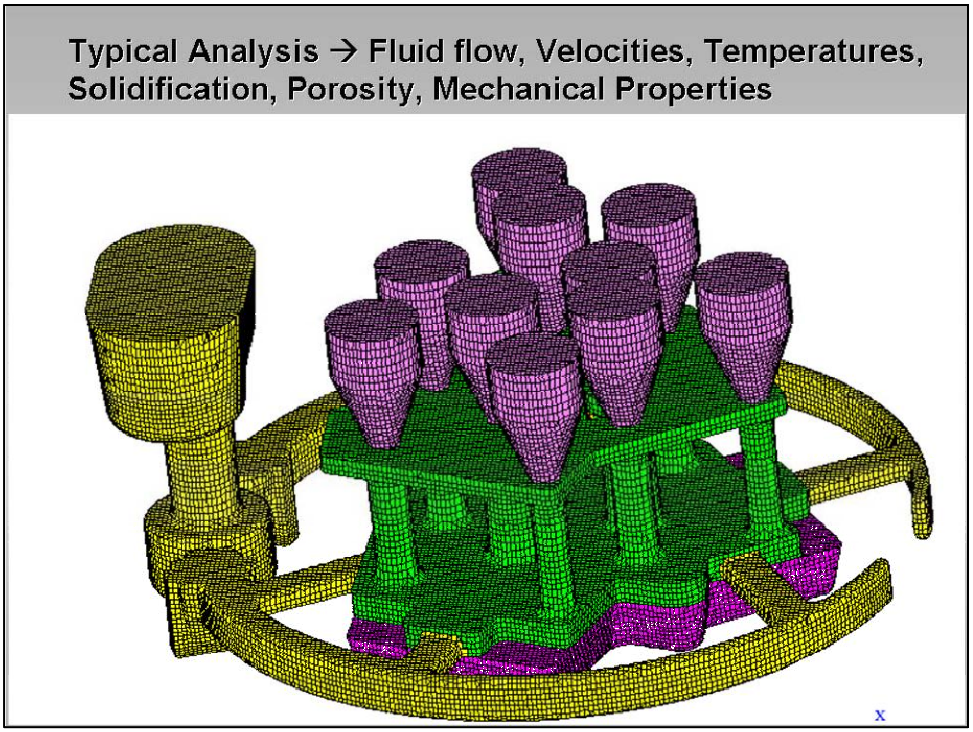
- Requirements and Specifications
- Preliminary Design
- Solidification Modeling
- Design / Manufacturing Review Meeting
- Detailed Design
- 3D Print Cores and Molds
- Pour at Foundry

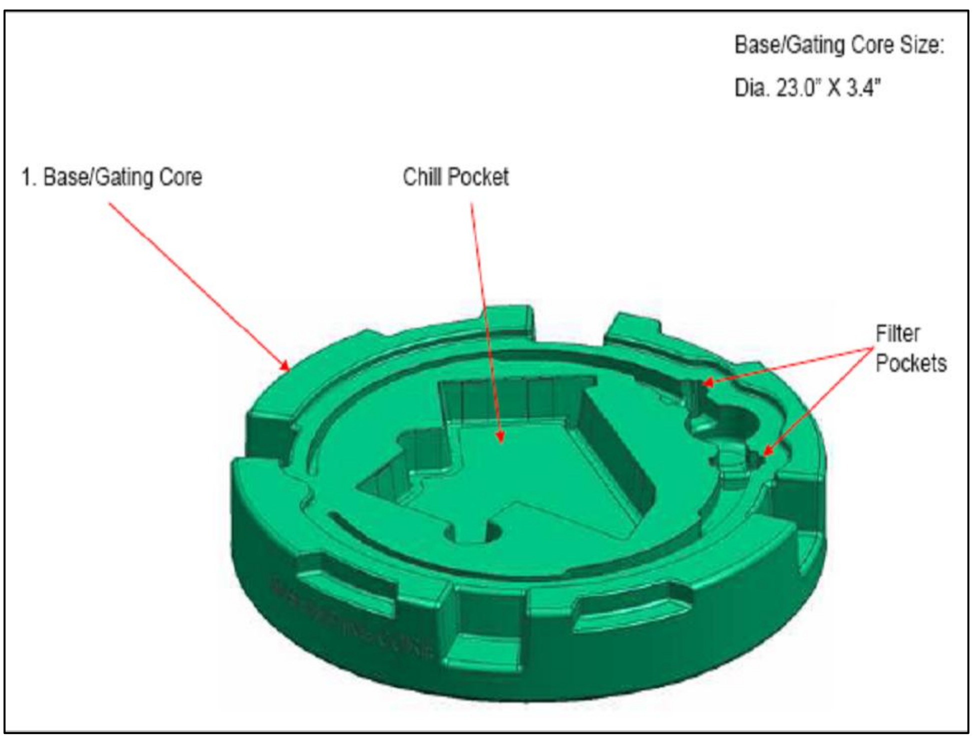
PROMETAL RCT RAPID CASTING TECHNOLOGIES

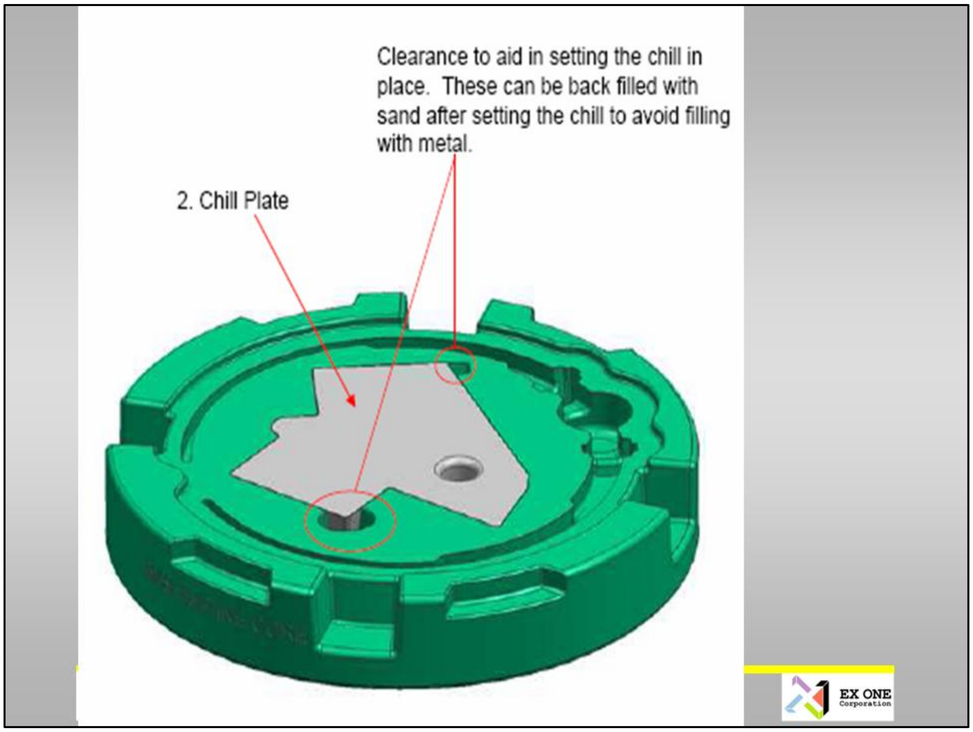
EX ONE Corporation

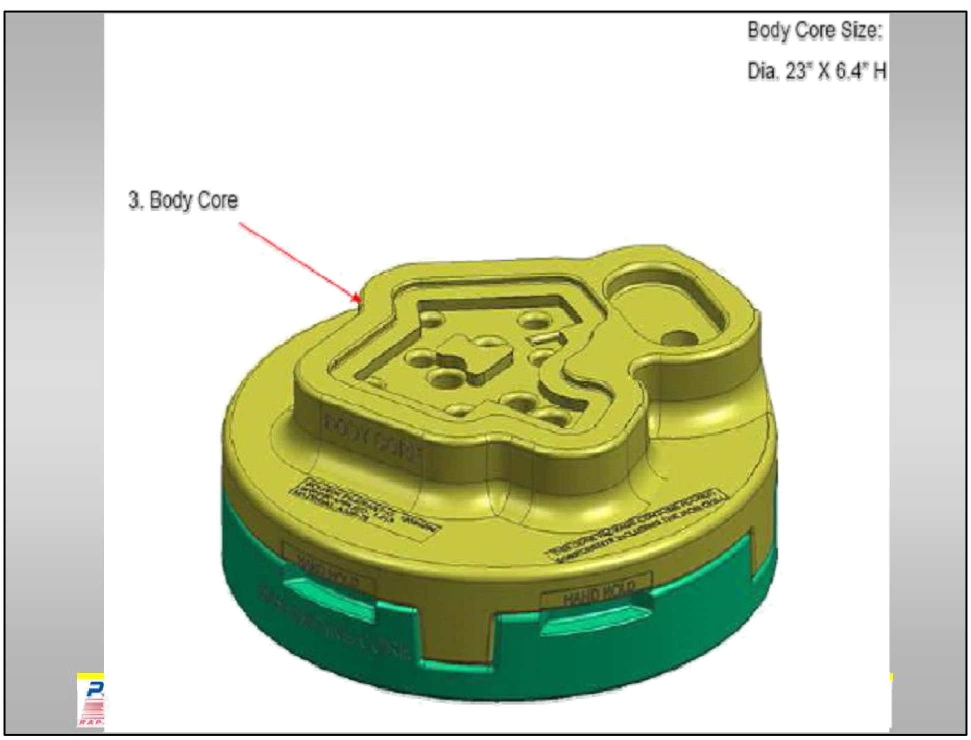

Feeder, Forward
Part No. 12524269
PROMETAL
RCT
RAPID CASTING TECHNOLOGIES
EX ONE
Corporation

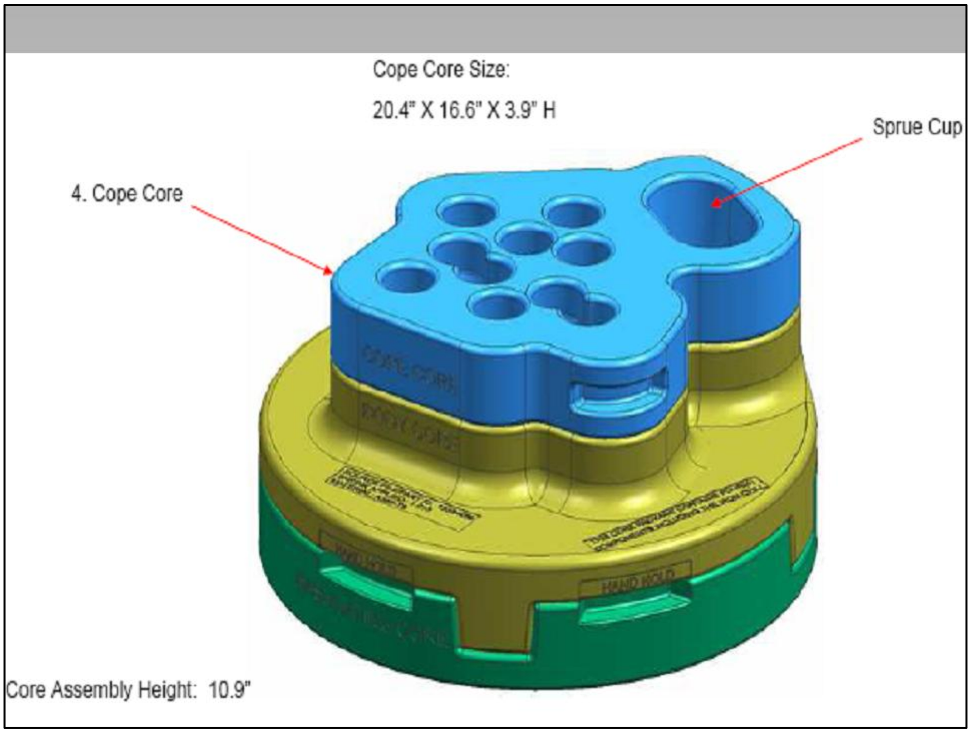

Preliminary Design Required for input to
Solidification Analysis

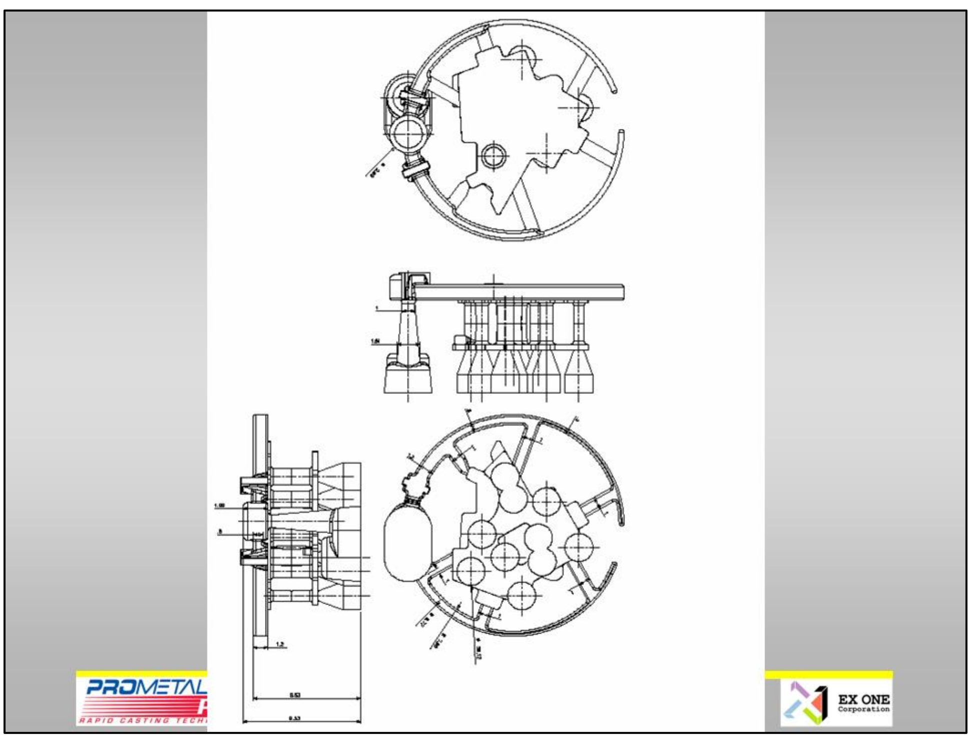

Typical Analysis → Fluid flow, Velocities, Temperatures, Solidification, Porosity, Mechanical Properties


Base/Gating Core Size:
Dia. 23.0" X 3.4"
1. Base/Gating Core
Chill Pocket
Filter Pockets

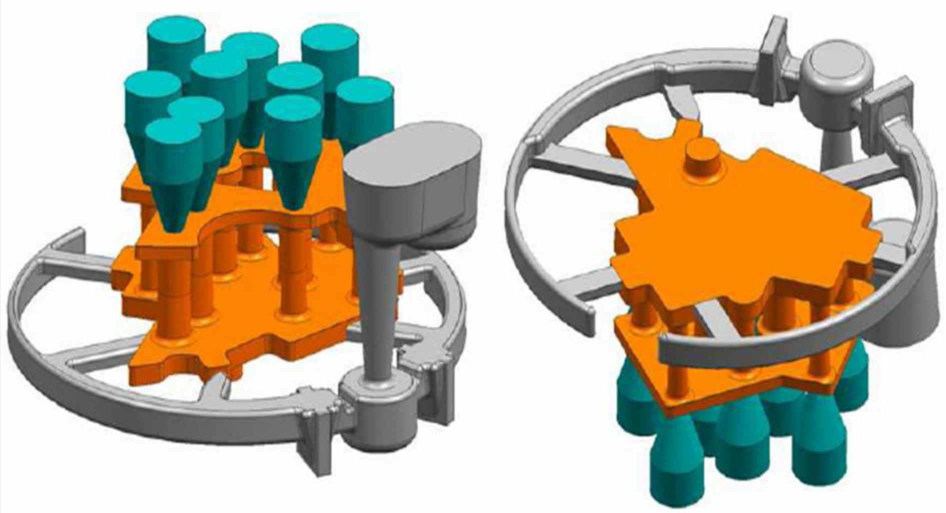

Clearance to aid in setting the chill in place. These can be back filled with sand after setting the chill to avoid filling with metal.
2. Chill Plate
EX ONE Corporation

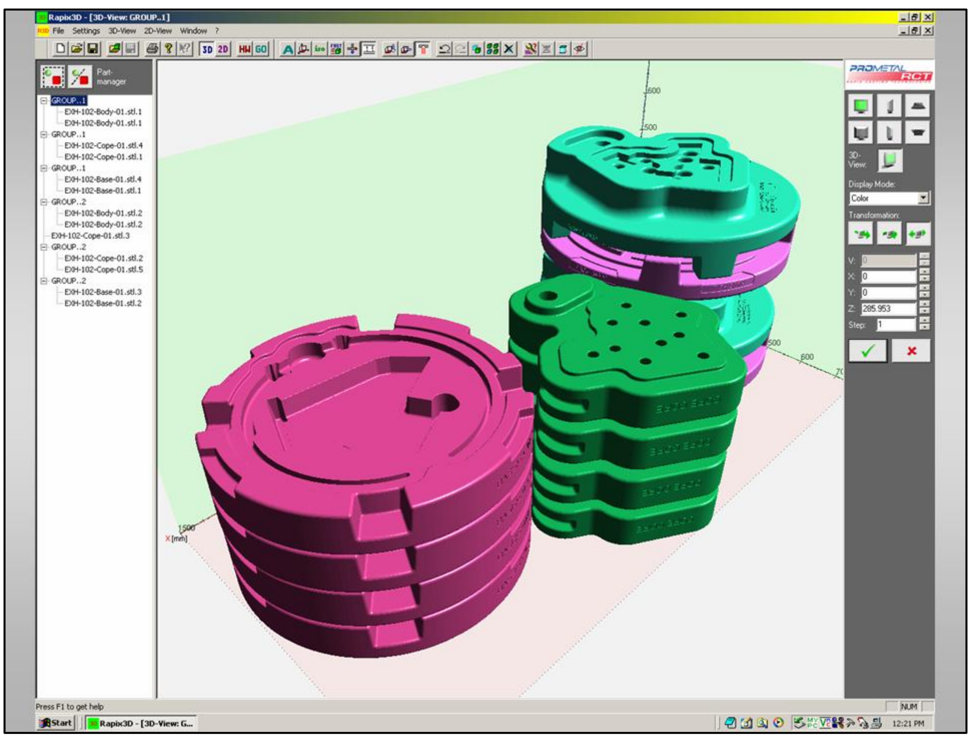

Body Core Size:
Dia. 23" X 6.4" H
3. Body Core
BODY CORE
HAND HOLD

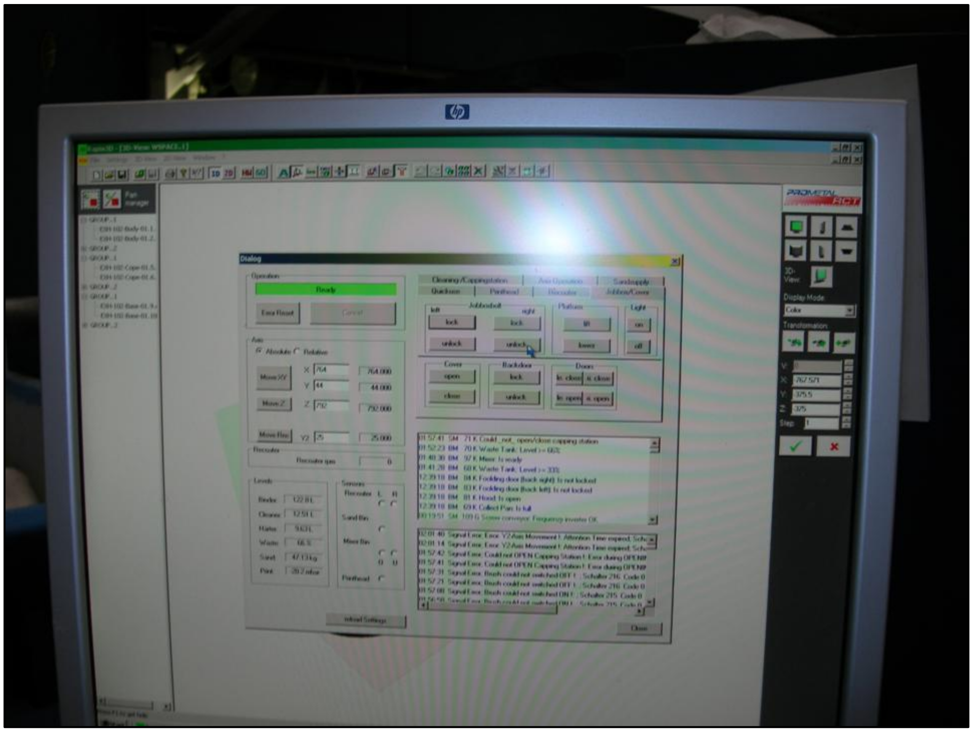

Cope Core Size:
20.4" X 16.6" X 3.9" H
Sprue Cup
4. Cope Core
COPE CORE
BODY CORE
HAND HOLD
Core Assembly Height: 10.9"

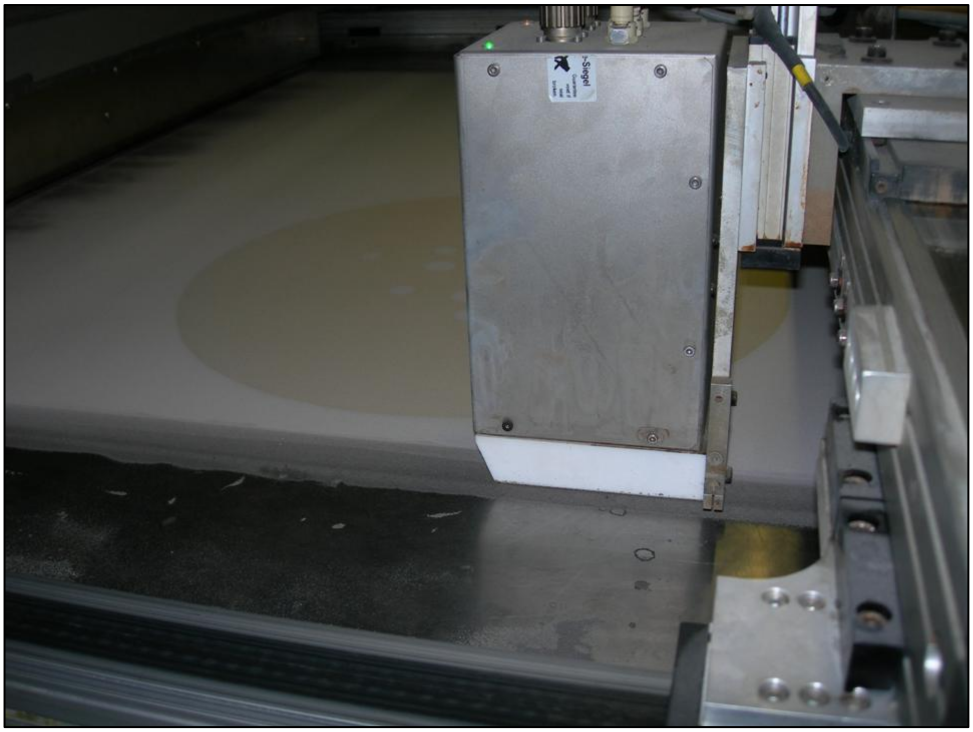

PROMETAL
RAPID CASTING TECH
EX ONE
Corporation

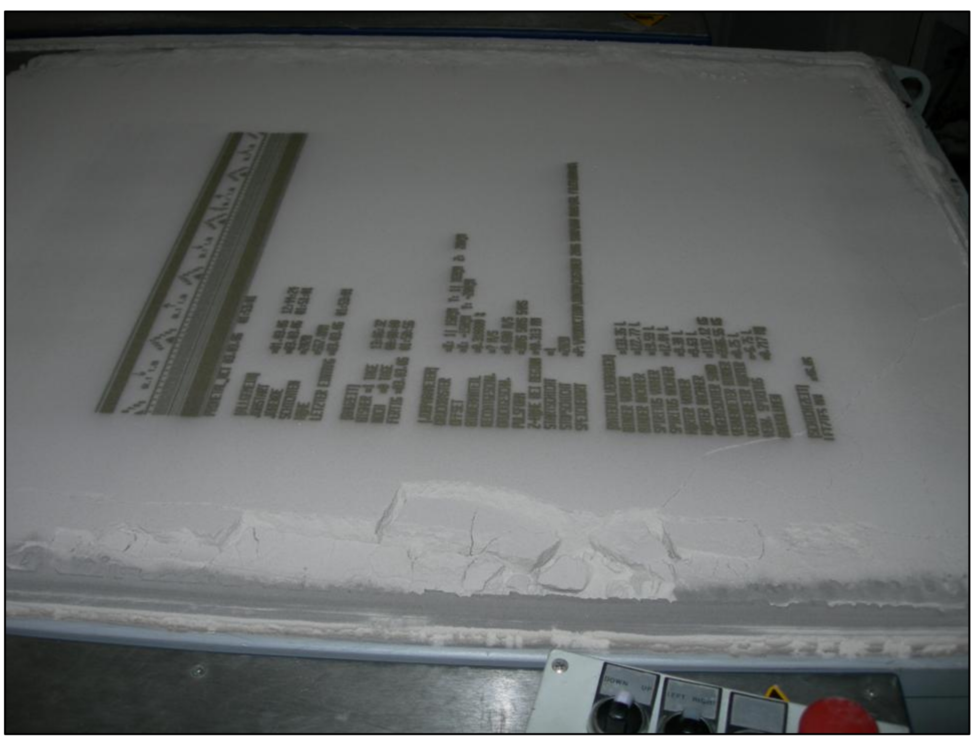
Entire Mold Package (cope, drag, core, sprue, cup, runners, gates, risers) Designed, Analyzed & Printed

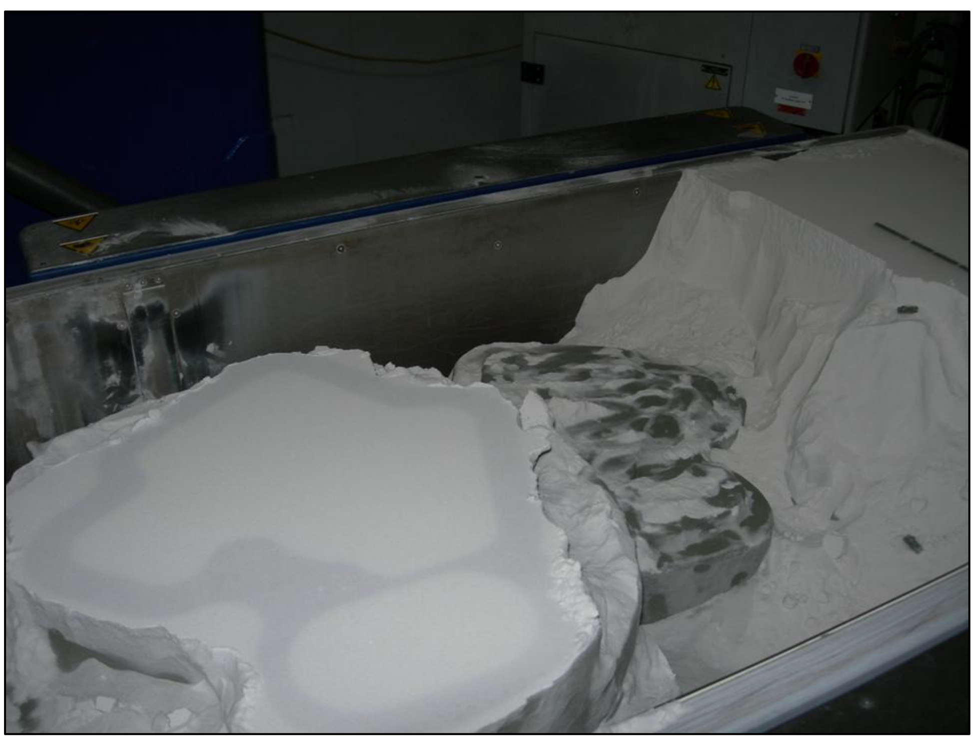


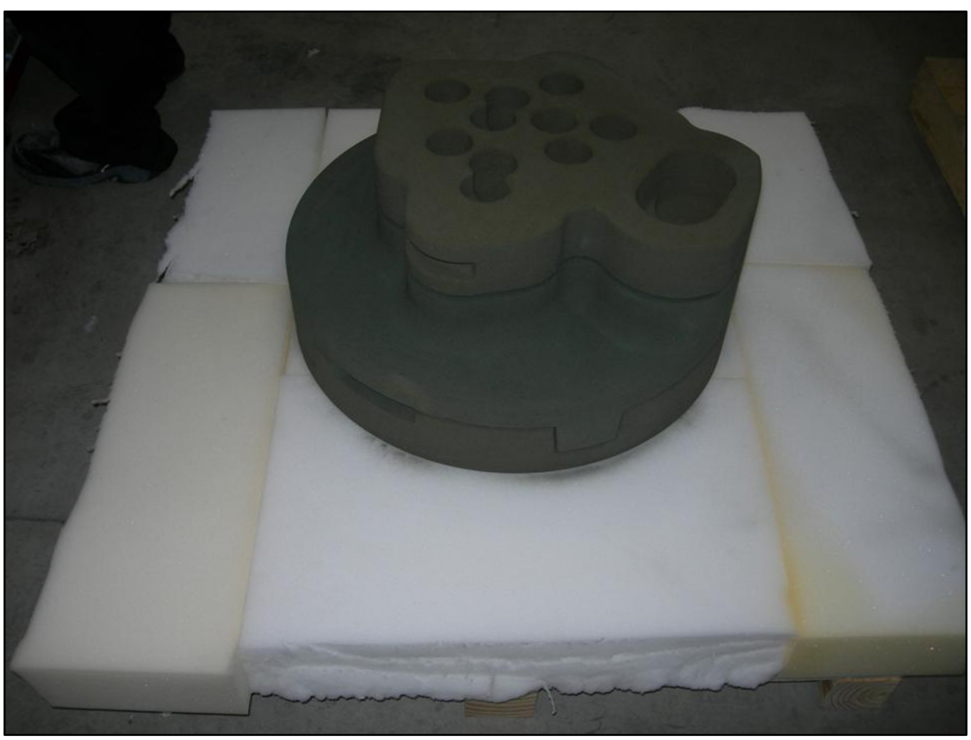












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APPENDIX D ACKNOWLEDGEMENTS

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ACKNOWLEDGEMENTS

The following individuals contributed to the success of the digital mold printing demonstration effort at Rock Island Arsenal. Thanks to all.

Alexander, Cory	Metallurgist	Rock Island Arsenal JMTC
Bellefeuille, Jim	Machine Operator	ProMetal
Brasch, Garry	Molder	Rock Island Arsenal JMTC
Cadengo, Julian	Machine Operator	ProMetal
Davidson, Leonard	Engineering Technician	Rock Island Arsenal JMTC
Doran, Jeff	CAD Support	Rock Island Arsenal JMTC
Erickson, Fred	Molder	Rock Island Arsenal JMTC
Fitzgerald, Mike	Process Development Specialist	Technikon
Fox, Jim	Radiograph	Rock Island Arsenal JMTC
Green, Donnie	Post Processing	Rock Island Arsenal JMTC
Kim, Chung, Whee	President	EKK, Inc.
Lembo, John	Production Manager	ProMetal
Lipovic, Curt	Chief, Hot Metals Division	Rock Island Arsenal JMTC
Maas, Dan	Technology Transfer	ProMetal
Martin, Shannon	Melter	Rock Island Arsenal JMTC
McDonald, Walt	Molder	Rock Island Arsenal JMTC
Mcgill, Ken	Machine Operator	ProMetal
McLaughlin, Marty	Applications Engineer	EKK, Inc.
O’Connor, Kevin	Systems Engineer (Environmental)	US Army ARDEC
Orange, Mike	Production Manager	ProMetal
Phillips, Curtis	Design Engineer	ATD
Rosenthal, Paul	Metallurgist	The Practical Metallurgist
Sands, Cliff	President	ATD
Standafer, David	Production Supervisor	Technikon
Stichter, Brian	Melter	Rock Island Arsenal JMTC
Stork, Jude	Business Development	Rock Island Arsenal JMTC
Tice, Don	Business Management Directorate	Rock Island Arsenal JMTC
Tucker, Jerry	Patternmaker	Rock Island Arsenal JMTC
Tuk, Doug	Machine Operator	ProMetal
Voss, Richard	Patternmaker	Rock Island Arsenal JMTC
Windschitl, Larry	Radiograph	Rock Island Arsenal JMTC
Wrazen, Mike	COR of CERP Program	US Army ARDEC
Zaiss, Dan	Melter	Rock Island Arsenal JMTC

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APPENDIX E ACRONYMS AND ABBREVIATIONS

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ACRONYMS AND ABBREVIATIONS

°C	Degrees Centigrade
°F	Degrees Fahrenheit
AFS	American Foundry Society
ARDEC	(US) Army Armament Research, Development and Engineering Center
ASTM	American Society for Testing and Materials
ATD	Advanced Tooling Design
CAD	Computer Aided Design
CERP	Casting Emission Reduction Program
CISA	Casting Industry Suppliers Association
CMM	Coordinate Measuring Machine
CNC	Computer Numerical Control
COR	Contracting Officer's Representative
CRADA	Cooperative Research and Development Agreement
DLA	Defense Logistics Agency
DOD	Department of Defense
DOE	Department of Energy
JMTC	Joint Manufacturing and Technology Center
MIL	Military specification
MIT	Massachusetts Institute of Technology
MSDS	Material Safety Data Sheet
NDT	Non Destructive Testing
QA/QC	Quality Assurance/Quality Control
RCT	Rapid Casting Technology
RIA	Rock Island Arsenal
SLA	Stereo Lithography Apparatus
SO_2	Sulfur Dioxide
USCAR	United States Council for Automotive Research
WBS	Work Breakdown Structure