Casting Emission Reduction Program
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US Army Contract DAAE30-02-C-1095
FY 2003 Tasks
WBS # 1.4.0

Second Phase Data Collection Required for Cost Benefit Analysis for New Product Development GMBOND®

Technikon # 1410-140

March 2005
(revised for public distribution – September 2005)

United States Environmental Protection Agency

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Technikon # 1410-140

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

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1.0 OVERVIEW

This Technical Report – Study/Services deliverable covers Phase Two testing for the GMBOND® Machine and Process. The Report provides data collected to date, explains how the GMBOND® project was established, and outlines the importance of the GMBOND® Machine and Process to the foundry industry. A new generation V8 engine block (GEN IV block) casting from General Motors (GM) that will go into full production in 2006 was used as a test part for this study. The GEN IV block is being produced using a precision sand process. Precision sand refers to molds that are made up of all resin bound sand cores. The current program is scheduled to start-up using ColdBox® or Phenolic urethane as the binder for the sand. Tooling was purchased to allow the GMBOND® machine to make the GEN IV block cover core. This core provides the opportunity to make a direct comparison of Cold BOX® and GMBOND® core costs and benefits.

Phase one tasking collected initial data, purchase and partially installed equipment, and identified the protocols needed for comparing GMBOND® and ColdBox® performances. Phase Two tasking gathered data between January 2004 and July 2004. Not all the data for a complete Cost Benefit Analysis (CBA) was collected during Phase Two tasking. A detail cost will be submitted after core making test results are finalized when Phase Three is completed in mid 2005.

The technical report for Phase Two tasking consists of two sections plus an appendix.

Section 1 of this report provides a Phase Two Overview. Included in this section are the Introduction, Phase Two summary, and Phase Two conclusions.

Section 2 comprises six subsections. Phase Two is a comparison between GMBOND® and ColdBox® for performances and cost efficiencies.

Section 2.1 explains the Sand Binder Process and some initial benefits identified in previous work.

Subsection 2.2 discusses the decision to use pre-coated sand rather than a just-in-time mix system. This is followed by a detailed explanation of the GMBOND® process involving storage bin and hoist, aging hopper, screw conveyer, core box, chiller, vacuum, and sand coating systems.

Subsection 2.3 identifies the additional equipment needed for GMBOND® process performance and testing. It also lists the equipment that has been purchased and assembled to provide maximum flexibility for optimizing the process.

Subsection 2.4 identifies the testing process, schedule, test equipment required, protocols or parameters utilized, initial test evaluations, and test conclusions. A discussion of what will be completed in Phase Three of the project is also provided in this section.

Subsection 2.5 describes the ColdBox® core making process.

Finally, subsection 2.6 describes the comparisons in performance and costs between GMBOND® and ColdBox®. A previous cost study is used to illustrate the potential cost/benefit of the GMBOND® process. At this time, the ColdBox® system at GM is completing debugging and initial start-up. The data parameters outlined in this report will allow a final cost/benefit analysis that is scheduled for completion during Phase Three of this study.

1.1 INTRODUCTION

With the need to maintain a viable foundry industry, the United States government sponsored research to identify ways foundries could comply with environmental regulations while maintaining casting quality and global competitiveness. A Cooperative Research and Development Agreement (CRADA) was drafted between the U.S. Department of Defense, the U.S. Environmental Protection Agency, the California Air Resources Board, and private sector organizations like the American Foundry Society, the Casting Industry Suppliers Association, and the United States Council for Automotive Research. The Casting Emission Reduction Program (CERP) was established in 1994 to address these issues.

It is CERP's mission to improve, develop, and/or demonstrate new products, processes, and technologies for the metal casting industry. The parameters of this mission are to reduce negative environmental impact and keep the industry competitive in a global economy. The research performed under CERP enables foundries to meet new environmental requirements while insuring an economical supply of quality castings produced in the United States. Technikon, LLC under contract to the US Army, operates CERP.

The Technikon foundry is located at McClellan Park, formerly known as McClellan Air Force Base, in the Sacramento Area in Northern California. Information and research data generated is shared with industry, helping to secure American jobs and our national industrial infrastructure.

This program has dedicated an enormous amount of time and effort in testing and developing new casting processes. A major effort has been the testing of new core processes. A process that demonstrated great promise, but has never been fully developed, is the GMBOND® process.

General Motors (GM) Research and Development (R&D) begin working on finding a new environmentally friendly sand binder system (GMBOND®) in the early 1990's. During the same period, GM Power train analyzed the lost foam process for the production of future engine castings. The initial GM sand binder R&D team formally presented the technology to the American Foundry Society Casting Congress. The binder was subsequently introduced to the U.S. metal casting industry in 1994.

In 1994, J. Michael Williams, head of GM Powertrain Manufacturing announced, "lost foam will be the aluminum engine block and head process of choice" (Modern Casting, Aug. 2000, page 31 "A History in Foam"). Although there were obvious merits to the new sand binder technology, GM Powertrain management had already made a decision to optimize the lost foam process. Nevertheless, between 1994 and 1996 GM's R&D group worked to develop the general process parameters to produce cores with the protein-based sand binder. They realized that, despite the Powertrain commitment to lost foam, their suppliers would have a need for this new

(GMBOND®) technology because of shakeout and environmental issues related to the phenolic urethane ColdBox® process.

GM conducted several validation trials between 1996 and 1999 with Teksid SpA, a large automotive casting supplier, and internally. Castings were made in green sand molds, with GMBOND® cores for cast iron ventilated brake rotors. Aluminum squeeze cast V6 engine blocks were produced in GMBOND® in an effort to determine dimensional and shakeout tendencies. Many green sand molded aluminum cylinder heads were produced with GMBOND® cores. Teksid and GM verified the shakeout of the process with a semi-permanent-mold aluminum suspension arm. In every case, the casting quality, surface finish, and shakeout were as good as or better than the phenolic urethane ColdBox® process. Despite this, GM was not in position to commercialize and optimize this technology for the foundry industry.

Because of their close relationship from past development work, Hormel Foods entered into an agreement with GM in December 1999. This agreement allowed Hormel to attempt to commercialize and develop the new technology. As Hormel was introducing this new technology, they were improving and refining the core making process.

CERP conducted air emissions testing of various new and improved core binders, including GMBOND®, indicated that GMBOND® produced significantly lower toxic air emissions than all other binders tested. Table 1-1 and Figure 1-1 compare GMBOND® with ISOSET®, a sulfur dioxide (SO) cured core, and ISOCURE®, a triethylamine (TEA) cured core.

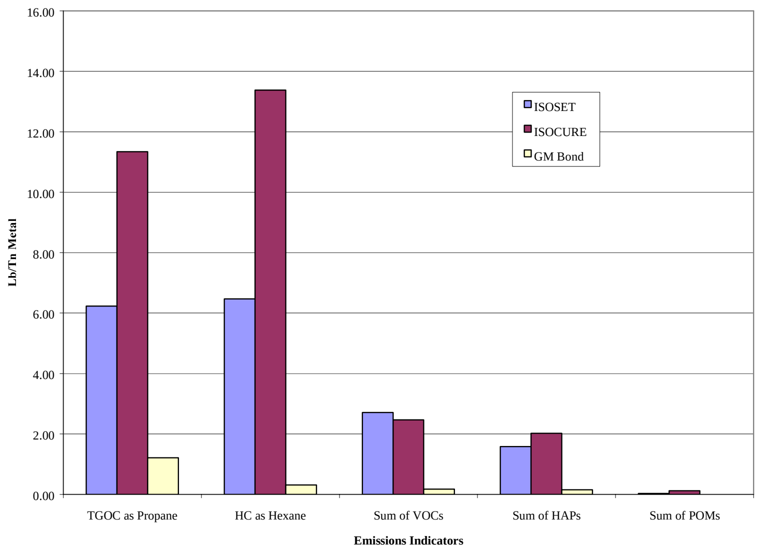
Table 1-1 Comparison Summary Average Results – Pouring/Cooling/Shakeout

Analytes	ISOSET® (Lb/Tn Metal)	ISOCURE® (Lb/Tn Metal)	GM Bond® (Lb/Tn Metal)
TGOC as Propane	6.23	11.3	1.21
HC as Hexane	6.47	13.4	0.308
Sum of VOCs	2.71	2.46	0.172
Sum of HAPs	1.58	2.02	0.154
Sum of POMs	0.028	0.119	<0.001
TNC as Aniline	NA	NA	0.459
Individual Organic HAPs			
Phenol	0.930	1.62	0.035
Cumene	0.425	NT	<0.001
Toluene	0.042	0.026	0.070
Ethylbenzene	0.037	0.003	0.005
o,m,p-Cresols	0.025	NT	0.017
Benzene	0.025	0.023	0.004
Methylnaphthalenes	0.024	NT	<0.001
o,m,p-Xylenes	0.014	0.029	0.004
Acetaldehyde	0.010	0.036	0.006
Styrene	0.009	NT	0.004
Naphthalene	0.004	0.119	<0.001
2-Butanone	<0.001	0.006	0.004
Aniline	NT	0.156	<0.001
Hexane	I	NT	0.005
Other VOCs			
a-Methylstyrene	1.01	NT	<0.001
Trimethylbenzenes	0.045	0.392	<0.001
Ethyltoluenes	0.027	NT	<0.001
Dimethylphenols	0.009	NT	<0.001
Butyraldehyde/Methacrolein	0.004	0.044	0.002
Octane	<0.001	0.004	0.007
Other Analytes			
Condensibles	2.45	4.07	1.47
1,6-Hexanediol Diacrylate	<0.001	NT	NT
Trimethylol Propane Triacrylate	<0.001	NT	NT
Methane	NT	NT	0.037
Carbon Dioxide	NT	NT	22.3
Methane (Blank)	NT	NT	0.038
Carbon Dioxide (Blank)	NT	NT	22.3

I: Data rejected based on data validation considerations.
NT: Not Tested.
All **"Other Analyses"** are not included in the Sum of VOCs or HAPs.
Individual results constitute >95% of mass of all detected VOCs.
* Blank sample refers to ambient background levels in building at time of test.

The US Army (CERP Manager) and the CERP Steering Committee agreed to direct CERP funding to purchase and install a machine designed specifically for the GMBOND® process at an operating foundry because of previous positive research results. These positive results included GM production tests, CERP environmental testing and a potential to recycle sand.

Figure 1-1 Comparison of Emission Indicators–Pouring/Cooling/Shakeout



1.2 SUMMARY

This partnership between the private sector and CERP is specifically designed to aid the competitiveness of the U.S. foundry industry. A successful demonstration of the new process at an active foundry will give the process a positive result in meeting the CERP objectives of complying with environmental regulations and maintaining casting quality and global competitiveness. Active support and cooperation of General Motors, CERP, Hormel, and the United Auto Workers were instrumental in obtaining the necessary approval and funding for a Department of Defense project to demonstrate the viability of the GMBOND® process. This resulted in a machine being installed at the General Motors Saginaw Malleable Iron (SMI) operations in Saginaw, Michigan.

The first dual-station, production-type, core-shooting machine developed exclusively for use with the GMBOND® process began installation at the General Motors Saginaw Malleable Iron operations on August 20, 2003. The first core produced from this machine occurred on February 17, 2004. This unique machine is design to accommodate all the core boxes required for the core package of the General Motors GEN IV engine block. This aluminum engine block is manufactured using the precision sand casting process. Currently, the GEN IV engine block is developed using the phenolic urethane (ColdBox®) process. This provides a unique opportunity to compare the costs and benefits of the existing accepted (ColdBox®) binder with the proposed GMBOND® properties. As the precision sand process is debugged for the GEN IV block, the available tooling allows GMBOND® cores to be substituted in the core package and direct comparisons evaluated.

1.3 CONCLUSIONS

Most Phase Two objectives for the evaluation of the GMBOND® process are archived. Two categories are examined for this project: performance effectiveness and cost efficiency.

There are four identified conclusions that influenced performance effectiveness.

1. Conductive heating and convective heating play a significant role in the curing of the "top" surface of the core; however, only conductive heating affects the sidewalls to any surface. Curing "Top" of core receives significant drying from the airflow through the core as well as the heat migrating from the tooling surface. The top sections cured are over twice as thick as the sections cured on the sidewalls. Reducing the amount of moisture gives a thicker cured section at a given purge time than would be expected if only the hot air purge was contributing to the drying. Curing the sidewalls of core indicates that it is controlled largely by the heat transfer from the tooling. The thickness of the cured sections in the sidewalls does not change significantly with changes in moisture or binder level. Only tooling temperature and purge heating time have an effect.

2. Sidewalls are hardened only by heat, which limits the cycle time for the cover core. The walls must support the core when it is sitting on the transfer table or the core machine or when the core is picked up by the hoist.

3. The cover core results indicate that a 1.00% binder level with 2.00% moisture level provides the most consistent quality core. Binder levels evaluated were 0.75%, 0.80%, and 1.00% with varying moisture levels. A minimum cycle time of 225-250 seconds (with only one set of tooling) is required to produce a cured core that will allow handling and removal from the machine.

4. A significant reduction of moisture in the core was observed when using the vacuum drying chamber after removal of the core from the core machine. After several minutes under the vacuum, the core is completely cured. Additional testing of applications for the use of the vacuum curing must be included in any future testing.

GM Power Train Group and GM R&D performed a cost analysis after their initial GMBOND® development. An estimated cost benefit of $3,000,000 was calculated when compared to ColdBox®. This is based on using silica to produce 500,000 castings per year.

Actual cost benefit analysis will be the outcome of the final report (Phase Three). There were no cost or energy comparisons during Phase Two between GMBOND® and ColdBox® because GM is still in the process of installing its equipment. A final analysis will be completed during Phase Three of this study. This will include: (1) Production related cost comparison between ColdBox® and GMBOND® (2) Energy comparison between ColdBox® and GMBOND® and (3) Environmental and OSHA comparison between ColdBox® and GMBOND®.

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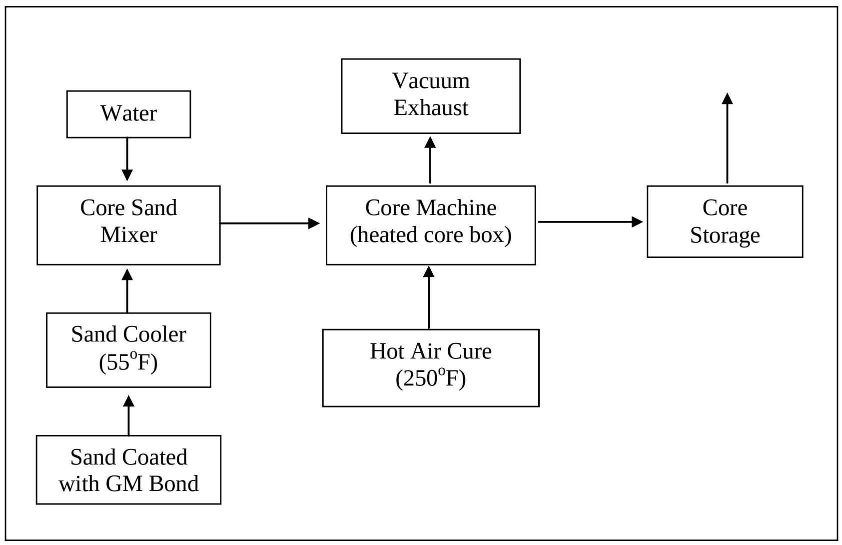
2.0 PROCESSES: GMBOND® versus ColdBox®

This section discusses the processes of GMBOND® and ColdBox®. Discussions for GMBOND® centered on its required equipment needed to operate the process and the testing equipment required for an evaluation. A GMBOND® test plan discusses its objectives, schedule, machine and sand parameters, initial evaluation, test conclusions, and Phase Three objectives. ColdBox® making process and its parameters are explained. Finally, the comparison between GMBOND® and ColdBox® are discussed in terms of performance and cost. Machine and process cycle times are designed to be competitive with current ColdBox® processes.

Figure 2-1 GM Bond Equipment Layout



2.1 GMBOND® SAND BINDER PROCESS

Studies in the past few years have shown that GMBOND® demonstrates several superior characteristics. Goals of the past GM research were to develop a binder that has numerous features: reduced odors and toxic gases, environmentally safe, repeatable recyclability, core strength comparable to current processes, good shelf life, reduced emissions, and easy shakeout from castings. GMBOND® Sand Binder consists mostly of animal-derived biopolymers that are combinations of amino acids linked together to form long chains called proteins. The binder is a dry, fine, tan, water-soluble powder. During the initial development, the amount of binder used to make a batch is 1% of the sand's weight. In order to make the binder become adhesive, water (2% of the sand weight) is required. Once water is added to the mixture, it has to be kept at 55^{o}F +/- 5^{o}F. Bonding is accomplished by dehydrating the wet core sand mixture. Biopolymers form covalent bonds as the water is removed from the core to form a crystalline structure. In this process, scrap cores can easily be reused because no chemical reaction has taken place. They just need to be broken down into fine grains again and put back into the system, requiring no extra binder.

Previous work indicates GMBOND® sand binder is easy to use, allows for complex core design, and is simple to clean up. Cores made with GMBOND® exhibit high strength and surface finish, and when properly cured, are easy to handle right out of the core box. Since the binder is completely soluble, water can be used to remove the core from the casting. Because cores dissolve in water, more intricate core geometries are possible. In addition, because acid demand value does not affect overall core strength, GMBOND® can be used with any type of sand.

Another benefit of using this binder is that water can be used to clean the core box because of the binder's water solubility. Material can simply be wiped away using a cloth. GMBOND® dramatically reduces shakeout problems, solid waste, and scrubber costs associated with current commercial binder systems. Phase Two of the project collected the necessary data to prove that a system specifically designed for GMBOND® provides the cost savings and environmental benefits that current data and testing indicated was possible.

The GMBOND® process (see Figure 2-1) at Saginaw Malleable Iron (SMI) foundry currently has tooling to produce the cover core (see Figure 2-2) for the GEN IV V-8 engine blocks. This core is the largest in the GEN IV core package that makes up the complete mold for the casting. This core weights approximately 230 pounds. The metal being poured is aluminum.

2.2 GMBOND® CORE MACHINE

GMBOND® core machine was designed as two separate components: the sand system and the GMBOND® core-shooting machine. (see Figure 2-3) This design was necessary due to the overhead space constraints that were presented to FATA Aluminum (designers and builders of the GMBOND® core machine) by the Saginaw foundry. Both the sand system and the core-shooting machine were designed to function independently to facilitate the myriad of research and development tests required for process optimization.

The sand system contains the different elements required to prepare the GMBOND® coated sand and transport the sand to the core machine. The process begins with coated sand entering from a storage hopper located directly above the mixer. This bin is designed to provide enough sand for approximately thirty minutes of production. It will hold the equivalent of three (3) tons of sand.

Figure 2-2 GEN IV Cover Core

Figure 2-3 Core-Shooting Machine

2.2.1 Storage Bin and Hoist

The bags of sand are picked up by the hoist and placed over the bin. They are set on a knife-edge located inside the hopper that rips the bag open allowing the sand to drop into the bin.

When the pre-coated sand is required for production, it is introduced into the chiller and then mixed with a measured amount of water. This equipment cools and hydrates the sand to its optimal operating condition. From the chiller, the sand travels into the mixer. The amount of sand required for each cycle was determined by the specific tooling. Currently, the GMBOND® project only has the tooling for the cover core. When the sand enters the mixer, water (2% of the sand weight) is added. After water is added to the mixture of sand and binder, the temperature must be maintained at approximately 55^{o}F. The mixing bowl has a water jacket that circulates water to cool the sand. The mixer disperses the water evenly through the sand thus increasing the sand's flowability.

Figure 2-4 Enclosed Belt Conveyor

Due to the limited operating space above the machine, the prepared sand is transported via an enclosed belt conveyor (see Figure 2-4). This specially designed conveyor maintains the sand temperature via cool air from the chiller while it is transported into the receiving hopper elevated above the shooting head loading station. This belt is equipped with a cleaning station to ensure that any sand remaining on the conveyor belt is removed for reuse. Like the sand mixer, the receiving hopper needs to be maintained at 55^{o}F. This is accomplished by a water jacket circulating water from the chilled-water system.

The core-shooting machine consists of the receiving hopper located above the shooting head of the machine, one core shooting station, two purging stations, and one core removal station. The receiving hopper stores the sand until it is ready for production. The receiving hopper acts as a preload station for the shooting head and facilitates the removal of any unused sand by discharging it into a sand-receiving flask. It is designed to allow for core unloading and core shooting taking place while a second core is in the air purge, or curing station. This allows for cycle time optimization consistent with customer demand.

2.2.2 Aging Hopper and Screw Conveyor

The shooting head moves transversely underneath the receiving hopper to receive a fixed amount of sand necessary for core production. Immediately before entering the shooting head, the sand is augured from the conditioning hopper. As shown in Figure 2-5, both the aging hopper and screw conveyor are insulated to insure the temperature stays at approximately 55°F. The shooting head is uniquely designed in that the sand is shot into the mold cavity. This is accomplished by forcing a metered amount of sand into the cavity via air pressure applied behind the sand column. This process reduces the total amount of air introduced into the cavity resulting in a more uniformly dense sand core.

Figure 2-5 Aging Sand Hopper above Core Machine

2.2.3 Core Box

The core box produces the specific shape of the individual cores. Two flasks make up every pattern: cope and drag. When connected together by clamps or pressure, they make up the pattern for the core. For the GMBOND® Core Machine, the core box is heated electrically. This is called a "warm box". The box will reach temperatures ranging from 200-300^{o}F.

Once the cavity of the mold is completely filled, the core box is sent to the purging station. At this station, the sand core is purged of moisture by the convection of warm air. Warm air that is injected into the core comes from two high-powered air dryers. Air attains an approximate temperature of 250^{o}F.

Figure 2-6 Air Dryers

2.2.4 Air Dryers

The machine and the core box are designed to facilitate air purging (see Figure 2-6) in different zones, either independently or simultaneously. This machine has been designed to allow the necessary flexibility to optimize the process by varying parameters until minimum cycle time and material use are established.

After purging, the cured core is transferred via the cope to a core unloading station where an operator deposits it onto a pallet for unloading. The operator uses a lifting mechanism (see Figure 2-7) to pick up the core and place it into storage. Later, the cope half is reattached to the drag half of the core box. Machine and process cycle times are designed to be competitive with current ColdBox® processes.

Figure 2-7 Cover Core Lifting Mechanism

2.3 GMBOND® ADDITIONAL EQUIPMENT

The commercial development of the GMBOND® system required equipment not normally used with the ISOCURE® (ColdBox®) process. This additional equipment was evaluated during the initial phase to allow future specification of the optimum system. A chiller system, vacuum system, and sand coating components are unique to the GMBOND® process. Processes for the equipment are explained in the following subsections.

2.3.1 Chiller System

The chiller system is essential in the GMBOND® core making process. Once the water is added to the sand and binder mixture, the mixed sand needs to be kept at approximately 55°F. This system supplies chilled water to the sand mixer, transporting conveyor, and to the receiving hopper. Areas that are not cooled with the chilled water are insulated to keep the sand at its operating temperature.

2.3.2 Vacuum System

Figure 2-8 Hormel Vacuum Assist System

Hormel provided equipment to produce a vacuum system (see Figure 2-8). This equipment was piped to the purge station on the machine. The vacuum assisted the core drying process by helping draw the moisture from the system. By providing this equipment, the cycle time that was required to produce a cured core was decreased. The benefits of vacuum for drying are well documented in the food industry. However, there are considerably less data on the benefit in core manufacturing. Previous GMBOND® tests without the vacuum system had cycle times for drying that were not competitive with the current

ColdBox® core-making process.

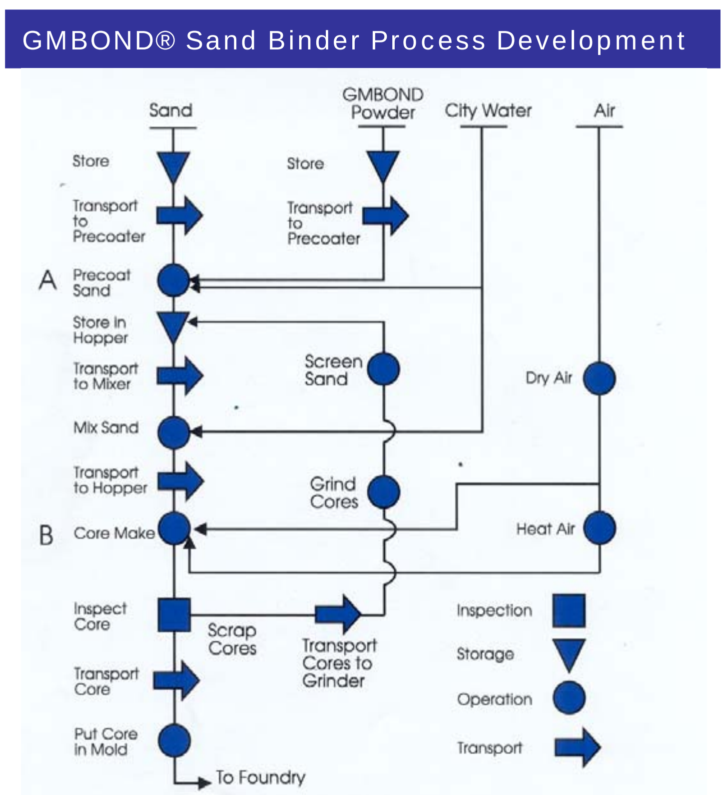
2.3.3 Sand Coating

Hormel Foods Corporation produces the sand binder that is used in the GMBOND® core process. It is manufactured in two ways: pre-coated sand or just-in-time mixing. Pre-coated sand is provided with the binder already mixed as a percentage of the sand weight. Just-in-time mixing is the more typical system where the binder is by itself, not mixed with sand. The company receiving the binder then has to have machinery that will correctly mix the binder with the correct sand quantity. The just-in-time mixing was removed and it was decided to receive pre-coated sand, in bags (see Figure 2-9). These bags weigh between 2,900-3,000 pounds. Figure 2-10 illustrates the process of pre-coating and use of GMBOND® sand in core making.

Figure 2-9 Coated GMBOND® Sand Bags

One of the goals is to determine the binder formulation and the most efficient percentage of binder use to produce properties as good as or better than the ColdBox® binder and for a lower cost and greater environmental benefit.

Figure 2-10 Pre-Coated Sand Method Preparation Flow Chart



2.4 GMBOND® TESTING AND DATA RESULTS

In Phase Two, analysis testing was accomplished on the cores and the equipment operating parameters. The core tests performed are Loss on Ignition (LOI), shell thickness versus purge time, tensile test, and core scratch hardness tests. This section discusses Phase Two testing objectives and process, schedule, testing equipment required, machine and sand parameters, initial test evaluations, and testing conclusions. Equipment parameters tested are discussed in subsection 2.4.3 (see Table 2-2).

2.4.1 Phase Two Testing

Phase Two analysis-testing objectives were determined in Phase One. Phase Two testing analysis consists of a core-testing machine, and parameter testing. Primary objectives for these tests were:

- Determine minimum cycle time to produce core.
- Evaluate dimensional stability.
- Initially evaluate casting function.
- Evaluate direct reuse of core, both directly crushed cores (core room scrap) and cores crushed after casting.
- Compare energy usage for GMBOND® and ColdBox® process.

In order to accomplish these objectives, a schedule was established with milestones identified.

2.4.2 Test Schedule

Testing was scheduled from March to July 2004. Testing was set for the weeks of March 29, April 19, May 17, May 24, and June 27 (2004). Table 2–2 depicts the start dates, test goals, and Phase Two objectives for each week. Testing lasted one week from the start of the test date followed by process and equipment changes and evaluation.

Table 2-2 Test Goals

Week	Tests	Phase Two Objectives
March 29	• Test changes in tooling to reduce vacuum leaks. • Make cores for casting test- castings to be made week of April 5th • Cut cores to evaluate dryness in different parts of the cores - keep broken cores for recycling tests. • Install data recording software.	• Determine minimum cycle time to produce core. • Initially evaluate casting function. • Evaluate direct use of core, directly crushed and cores crushed after casting. • Compare energy usage for GMBOND® and ColdBox® process.
April 19	• Evaluate methods to reduce cycle time – cut cores to evaluate dryness. • Collect cores for recycling tests. • Make cores to evaluate dimensional stability of cores at SMI. • Evaluate core box vacuum leaks with sonic leak detector	• Initially evaluate casting function. • Determine minimum cycle time to produce core. • Evaluate direct use of core, directly crushed and cores crushed after casting. • Compare energy usage for GMBOND® and ColdBox® process.

Table 2-2 Test Goals

Week	Tests	Phase Two Objectives
May 17	• Test vacuum equipment changes	• Initially evaluate casting function. • Determine minimum cycle time to produce core. • Evaluate direct use of core, directly crushed and cores crushed after casting. • Initially evaluate casting function.
May 24	• Test reuse of ground cores. • Continue to evaluate methods to reduce cycle time – vacuum and/or additional hot air.	• Determine minimum cycle time to produce core. • Evaluate direct use of core, directly crushed and cores crushed after casting.
June 27	• Continue to evaluate methods to reduce cycle time. • Make cores for casting trials. • Save cores from casting trials for recycle tests. • Send cores to be crushed for recycling tests.	• Determine minimum cycle time to produce core. • Evaluate direct use of core, directly crushed and cores crushed after casting. • Compare energy usage for GMBOND® and Cold-Box® process.

2.4.3 Machine and Sand Parameters

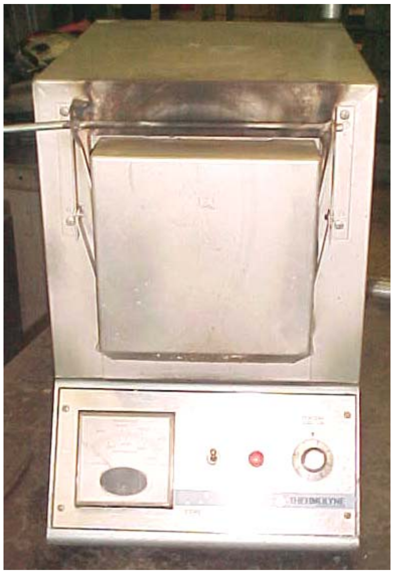
Machine and sand parameters for the GMBOND® process were compared with those of the ISOCURE® (ColdBox®) process for the cover core. The parameters recorded are listed in Table 2-3.

Table 2-3 Machine and Sand Parameters

Parameter Name	Parameter Name
Batch size:	Mix time:
Blow time:	Blow pressure:
Core box temperature:	Purge time:
Purge pressure:	Purge temperature:
% Binder vs. Sand weight:	Binder cost per bag:
Mixed sand price/ton:	Sand temperature:
Air quantity per cycle:	Core weight:
Cycle time:	Core shelf life:

The data in the parameters are variable to insure the production of a quality, competitive core, and to decrease the cycle time as much as possible. Each time a parameter was changed, tests were performed on the cores to evaluate how the changes affected the cycle time and the quality.

Figure 2-11 LOI Furnace



2.4.4 Test and Equipment

Cores were tested for the various parameters listed in Table 2-3. Core tests performed are Loss on Ignition (LOI), shell thickness versus purge time, tensile-test, core scratch hardness test, and shelf life.

The Loss on Ignition test determined the percentage of binder that is present on the sand. A sample of sand is taken out of the sand system and taken to the Metallurgy Lab. Fifty grams of the sand-binder mixture is weighed on a scale, and put into a cup. The cup is then put into the furnace (see Figure 2-11) where it is heated to approximately 1,800^{o}F. The mixture is kept in the furnace for approximately two hours. Once the time is elapsed, the cup is removed from the furnace and set aside until cooled. After the cup is cooled (and can be handled), it is placed on the scale and weighed. The difference between the two weights is the amount of binder that is burned off the sand.

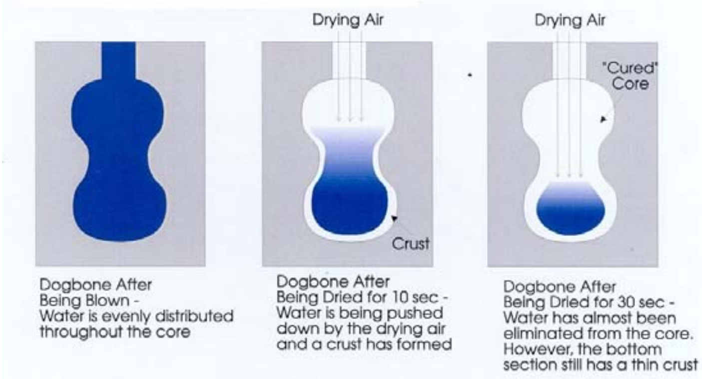
One of the most crucial test parameters on this core is the shell thickness, a measure of curing versus purge time. This test determines the overall cycle time. Once the core is out of the machine, it is cut open to determine the thickness of the shell. The shell is the part of the core that is completely dehydrated of water and has the core strength properties.

Figure 2-12 Tensile Test Device

A tensile test (see Figure 2-12) is used to determine the strength of the sand-binder mixture. One sample of the sand mixture was taken out of the system and placed into a sand blower device. This device blows the sand into a dog bone shape (See Figure 2-13). The sand blower device (see Figure 2-14) dehydrates the water from the sand to give it strength. Once the cycle time for this machine is completed, the operator takes the dog bone out of the machine. The dog bone is placed into the tensile test device and is pulled horizontally until the core fails. The operator then records the strength from reading of the indicator on top of the equipment.

A core scratch hardness test (see Figure 2-15) was performed on the cores. This determined the strength of the cores outer surface. The equipment used is set on the surface of the core. Next, the gauge is zeroed out. To use the device, the knob on the top of the equipment is rotated one revolution. The gauge then provides a hardness measurement of the core.

Figure 2-13 Dog Bone Curing and Testing Process (Hormel)



All these tests were compared to similar data for the ISOCURE® (Cold-Box®) process. The GMBOND® process goal is to equal or surpass the standards set by ColdBox®. Once the testing stage is complete, GMBOND® can produce cores. GMBOND® cores are used in production to evaluate what the reaction is once aluminum contacts the surface. Modifications will be made, if needed.

Figure 2-14 Sand Blower Equipment

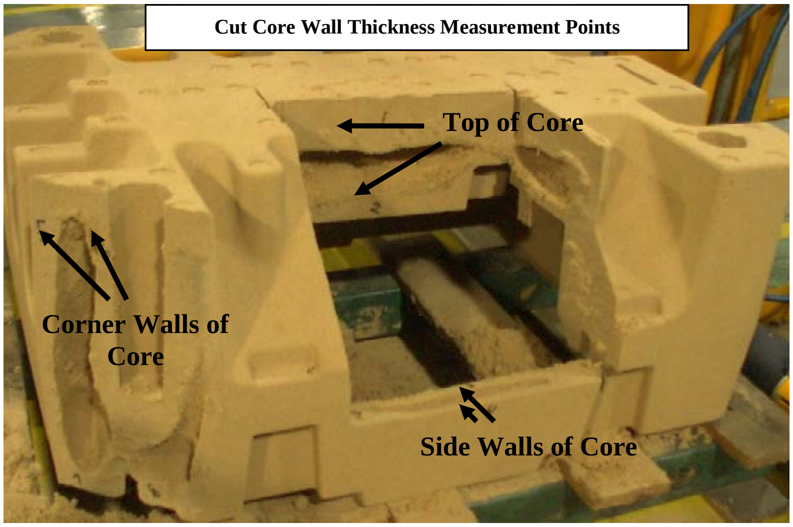
2.4.5 Evaluation of Tests

Tests conducted from March to August 2004 allowed the overall objectives to be addressed. While not all of the objectives were accomplished, a good understanding of the process was developed and a plan for future work was established. Many modifications to the tooling and the core machine will be made because of the testing results in an attempt to optimize the process.

With the current tooling, it is clear that the best cycle time that is achieved for the current cover core is approximately 250 seconds. Cycle times as low as 180 seconds were infrequently accomplished. A cycle time with the machine equipped with two sets of tooling would equate to approximately 2 minutes (120 seconds). This time could be reduced to 90 seconds with equipment modification and some post curing with an external vacuum system. Figure 2-16 depicts the areas that were not cured in the machine. These areas would require post curing (external heat or storage of 12+ hours). See Appendix A for actual dimensions of core wall thickness at different operating parameters.

Figure 2-15 Core Hardness Device

Figure 2-16 Core Wall Thickness Measurement Points



A positive result of testing was that the crushing allowed the sand to be returned to the sand hopper, therefore recycling all core-room sand scrap. No additional binder is required and core quality produced is very close to that of newly coated sand.

Reclaim test on cover core from a poured casting was conducted. After setting overnight, the poured cores were stripped from the castings. Burn-in was much greater than anticipated. The initial strength testing of this sand indicated it would not be sufficient to produce good cores. Future testing is planned when more normal production conditions are possible. Then the cover cores will be stripped within minutes of being poured. It is hoped that this will result in a less detrimental impact on the sand binder.

Tests cores for determination of dimensional properties were produced and evaluated by both SMI and the Casting Development and Validation Center's (CDVC) pattern shops. The results are acceptable for the process requirements.

Poured cores easily broke down in the shakeout system. Even with the ease of shakeout, the core retained good strength during the pouring operation.

While some energy data were obtained for the GMBOND® processes (see Appendix B), no comparison could be made to the ColdBox® process since General Motors is still in the process of installing its equipment. It is planned to instrument the individual pieces of equipment for both the GMBOND® and the ColdBox® process in the future to allow a comparison of energy use and cost.

2.4.6 Test Conclusions

The variables of time, temperature, moisture content, percent binder level, and vacuum all have an impact on the quality of core that is produced. Test teams were able to make four conclusions for cores with heavy sections (cover core was the source of the reported data).

1. Tests indicate that both conductive heating and convective heating play a role in the curing of the " top" surface of the core while only conductive heating appears to impact the side walls to any degree.

a) **<u>Curing "Top" of core:</u>** This area receives significant drying from the airflow through the core as well as the heat migrating from the tooling surface. The top sections cured are over twice as thick as the sections cured on the sidewalls. Reducing the amount of moisture gives a thicker cured section at a given purge time.

b) **<u>Curing sidewalls of core:</u>** Data indicate that the heat transfer from the tooling largely controls the curing of the sidewalls. The thickness of the cured sections in the sidewalls does not change significantly with changes in moisture or binder level. Only tooling temperature and purge heating time have an effect.

2. Sidewalls hardened only by heat from the tooling surface limits the cycle time for the cover core because it is the walls that must support the core, when it is sitting on the transfer table or the core machine, and when picked up with the hoist. The overall result is that with the current core geometry, a minimum cycle time of 225-250 seconds (with only one set of tooling) is required to produce a cured core that will allow handling and removal from the machine.

3. Binder levels of 0.75%, 0.80%, and 1.00% were evaluated with varying moisture levels. For the cover core, the results indicate that a 1.00% binder level with 2.00% moisture level provides the most consistent quality core. If lighter cores are tested, it will be necessary to rerun the binder levels and moisture levels to determine the optimum level for quality and cure time.

4. The use of the vacuum drying chamber after removal of the core from the core machine provided a significant reduction of moisture in the core. After several minutes under vacuum, the core is cured. Additional testing of applications for the use of vacuum curing must be included in any future testing.

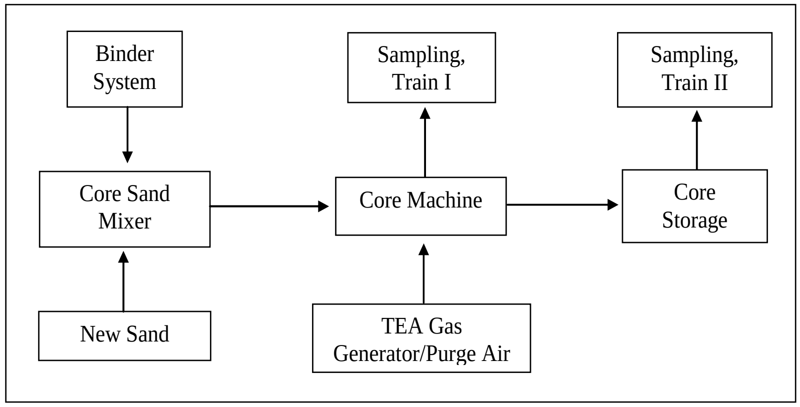
At this time, most Phase Two objectives for the evaluation of the cover core are achieved. Some energy data was obtained for the GMBOND® processes (see Appendix B), however, there was no comparison made with the ColdBox® process because General Motors is still in the process of installing its equipment. While additional refinements could be achieved, either they must address tooling changes that have been made to the ColdBox® production cover core or another production core must be selected for evaluation.

Phase Three testing will attempt to improve on cycle times, test reuse of bonded sand in making cores and run casting tests with GMBOND® cover cores. It is planned in the future to conduct a comparison of energy use and cost. A decision will be made later to attempt to modify the existing tooling to remove 90 lbs from the core package (matching the production ColdBox® cover core) or procure another core box for a different core in the Generation IV core assembly.

2.5 COLDBOX® MAKING PROCESS

The current core making process at Saginaw Metal Casting Operations (SMCO) is called ISOCURE® (ColdBox®). This is the process (see Figure 2-17) against which GM-BOND® process is being compared. Both processes are used for what is called Precision Sand, which means the entire mold package is made up of cores instead of the combination of cores set in green sand molds. The ISOCURE® process has the tooling for all of the cores in the V-8 engine block core package. A cover core that is produced at SMCO will be the focus of this section. This section will discuss the binder, sand and machine parameters, as well as the process that is currently under development for the GEN IV ISOCURE® (ColdBox®) equipment.

Figure 2-17 Cold Box Equipment Layout



2.5.1 The Binder

In the ISOCURE® process, the binder is a resin that consists of two liquid parts. The two liquids are labeled Part I and Part II. Like the GMBOND® process, this binder is currently being tested at 1% of the sand's weight. To make up that one percent, the ratio of Part I to Part II is 55/45 for every batch. This binder is mixed with the sand just before the core making. Once mixed with sand, it must be made into a core within approximately 12 hours (depending on the humidity) or the binder characteristics diminish and quality is reduced. This is very different from the GMBOND® process where the binder is present in the sand for an indefinite period until water is added.

One benefit of the ColdBox® binder is that it is not dependent on the sand being held to a cool temperature (55^{o}F) as in the GMBOND® process. Since this is the case, a chiller system is not required.

2.5.2 Process

The process of the ISOCURE® Core Machine (Figure 2-17) is very similar to the GMBOND® Core Machine. Sand starts in a storage hopper. From the hopper the sand travels into the mixer where the resin is added. Resin (1% of the sand weight) is then measured into the sand and mixes for 60 seconds. Since water is not a part of the binder system, none is added. From the mixer, the sand travels to the blow hopper where it is ready to be blown into the core box. The core box is called a "ColdBox®" since no external energy is required to heat it. Because the cover core is very large, the previous steps have to be repeated twice to complete one cycle. The core weighs approximately 230 pounds. With the existing machine for this process, a batch of sand is limited to approximately 150 pounds requiring two consecutive blows per core. Once the core is fully blown the core box stays in its position and the shooting head rotates to allow the purging head to get into place. GMBOND® process purges with hot air, while ColdBox® process purges with triethylamine (TEA) gas. The TEA gas is blown through the core, hardening it to make it usable for production. Once the core is through purging, it is released from the core box similar to the GMBOND® process. A lifting device is used to set the cores onto boards for storage.

Unlike the GMBOND® process, a chemical reaction takes place once the TEA gas is pushed through the sand. Since a reaction takes place, sand reclamation is very difficult to do. It is very expensive and time consuming. Since this is the case, every scrap core that is produced is thrown away instead of being reused. Sand recycling is one of the benefits of the GMBOND® process and dramatically reduces the cost of the sand and binder.

Other factors that are involved with ColdBox® process are toxic emissions and additional ventilation costs. In order to run this machine, ventilation must be present for the operator and its surroundings. This equipment is very expensive and it is time-consuming to obtain the necessary permits for installation. GMBOND® process does not require this equipment, thus it reduces the initial cost and potentially eliminates permitting issues.

2.5.3 Machine and Sand Parameters

The machine and sand parameters with data for the ISOCURE® (ColdBox®) core process for the cover core are listed in Table 2-4.

Table 2-4 Machine and Sand Parameter Data

Parameter Name & Data	Parameter Name & Data
Batch size: 146 lbs.	Sand temperature: not required
Mix time: 60 seconds	Gas type: TEA gas
Blow time: 6 seconds (total)	Gas quantity per cycle: 90 cubic centimeter (cc) / (0.143 lbs)
Blow pressure: 3 bar (44 psi)	Core weight: 230 lb.
Core box temperature: not required (ColdBox®)	Cycle time: 109 seconds
Purge time: 90 seconds	Core shelf life: 4-6 wks
Purge pressure: 4 bar (59 psi)	Historical Part 1 plus Part 2 cost is $0.75-0.85/ lb.
Purge temperature: not required	Gas cost: $0.85 per lb.
% Binder vs. Sand weight: 1%	Mixed sand price/ton: $45-72

Current research and testing of the ColdBox® process has provided these parameters to produce the cover core. When all of the data are available, a more comprehensive cost/benefit comparison of GMBOND® versus ColdBox® will help evaluate the potential for GMBOND®.

2.6 GMBOND® VERSUS COLDBOX®: COST AND PERFORMANCE COMPARISON

A general discussion on the Performance Effectiveness and Cost Efficiency is provided in the following subsections.

2.6.1 Performance Efficiency

Several categories were identified in which GMBOND® has an advantage over ColdBox®. These categories are improved recycling of scrap core, reduced toxic emissions and reduced need for ventilation equipment, increased core strength, easy shakeout of casting, good shelf life, and improved environmental safety.

The GMBOND® process (see Figure 2-1) purges with hot air, while the ColdBox® process (see Figure 2-17) purges with triethylamine (TEA) gas. A chemical reaction takes place once the TEA gas is pushed through the sand. Sand reclamation is very difficult to accomplish because a chemical reaction takes place. It is very expensive and time consuming. Every scrap core that is produced is thrown away instead of being reused. Sand recycling is one of the benefits of the GMBOND® process and dramatically reduces the cost of the sand and binder.

Other advantages of the GMBOND® over the ColdBox® process are reduced toxic emissions (see Figure 1-1) and reduced ventilation costs. In order to run the ColdBox® process, ventilation must be present for the operator and the surrounding area. Ventilation equipment air emission permitting is time consuming and expensive. GMBOND® process does not require this equipment, thus it reduces the initial cost and saves time.

GMBOND® sand binder is easy to use, allows for complex core design, and is simple to clean up. Cores made with GMBOND® exhibit high strength and surface finish and when properly cured and are easy to handle right out of the core box. Since the binder is completely soluble, water can be used to remove the core from the casting. Because cores dissolve in water, more intricate core geometries are possible. In addition, acid demand value does not affect overall core strength and GMBOND® can be used with any type of sand.

Another benefit of using this binder is that water can be used to clean the core box because of the binder's water solubility. Material can simply be wiped away using a cloth. GMBOND® dramatically reduces the shakeout problems, solid waste, and scrubber costs associated with current commercial binder systems (see Table 1-1 and Figure 1-1).

GMBOND® is environmentally safe because it has minimal emissions, it has no acid demand value, no ventilation equipment is required, the binder is soluble, water is used to remove the core from the casting, and a cloth is used to wipe away material.

There were no comparisons made of energy use between GMBOND® and ColdBox® processes because General Motors was in the process of installing its equipment (see Appendix B).

2.6.2 Cost Efficiency

During the initial development of the GMBOND® process, a cost analysis was performed by GM Powertrain Group and GM Research and Development. This study indicates that GMBOND® is competitive and provides a savings when used in an all precision sand package.

Table 2-5 tabulates the results of this previous study. Based on the study GMBOND® provides approximately a $3,000,000 per year cost saving over the ColdBox® precision sand process. As noted in the study, these savings are based on using silica sand producing 500,000 castings per year.

The current plan is to use lake sand instead of silica sand for both the ColdBox® and the GMBOND® processes. The same production level of 500,000 units is used in calculating the cost benefit of GMBOND® versus ColdBox®. Currently, the cover core is the only tooling available for GMBOND®. Therefore, the calculation is based on a comparison of costs for the cover core only. Ranges of prices will be used since the optimum formulation and binder percentage are not known at this time. Table 2-6 indicates that an annual cost savings in material usage and disposal are in a range from $1,968,225 to $2,490,325. This is based on the ability to reclaim 80% to 90% of the cover core sand and to reuse it with only the addition of water; which will be verified in Phase Three.

Table 2-5 Cost Comparisons – GMBOND® & Silica Sand (ColdBox®)

GMBOND® V8 Blocks (Silica Sand)			
Volume (pts/year)	500,000	SUBTOTAL $/ton PUCB BINDER	$18.00
Casting Weight (LB)	90	SUBTOTAL $/ton PUCB Amine*	$19.48
Sand to Metal Ratio	5.5	TOTAL PUCB $/TON	$37.48
Binder Additon (%BOS) PUCB	1.20%	Cost/ton GMBOND®	$74.25
Binder Cost ($/LB) PUCB	$0.75	Sand (LBS/YR)	247,500,000
Binder Addition (%BIX) GMBOND®	0.75%	Sand (TONS/YR)	123,750
Binder Cost ($/LB) GMBOND®	$4.95	Binder PUCB (LBS/YR)	2,970,000
Sand Cost ($/TON)	**$60.00**	Binder GMBOND® (LBS/YR1)	946,688
Reclamation ($/TON)	$25.00	Binder GMBOND® (LBS/YR2+)	928,125
Sand Loss (% BOS reclamation)	**10.00%**	Scrap Cores % PUCB	5.00%
Scrap Rate (% of Shakeout)	0.00%	Scrap Cores % GMBOND®	0.10%
Casting Cost ($/CASTING)	$150.00	Reuse GMBOND® %	50.00%
Cost Breakdown GMBOND® YEAR 1		**Cost Breakdown GMBOND® YEAR 2**	
Sand ONE WEEK SUPPLY	$148,500	Sand ONE WEEK SUPPLY	$0
Binder REUSE AFTER WK 1	$4,686,103	Binder	$4,594,219
Reclamation *	$1,048,134	Reclamation	$1,048,056
Sand Loss	$371,250	Sand loss	$371,250
Scrap Cores	$9,188	Scrap Cores	$9,188
TOTAL GMBOND®	**$6,263,175**	TOTAL GMBOND®	**$6,022,713**
PUCB V8 Blocks (Silica Sand)			
Volume (pts/year)	500,000	SUBTOTAL $/ton PUCB BINDER	$18.00
Casting Weight (LB)	90	SUBTOTAL $/ton PUCB Amine*	$19.48
Sand to Metal Ratio	5.5	TOTAL PUCB $/TON	$37.48
Binder Additon (%BOS) PUCB	1.20%	Cost/ton GMBOND®	$74.25
Binder Cost ($/LB) PUCB	$0.75	Sand (LBS/YR)	247,500,000
Binder Addition (%BIX) GMBOND®	0.75%	Sand (TONS/YR)	123,750
Binder Cost ($/LB) GMBOND®	$4.95	Binder PUCB (LBS/YR)	2,970,000
Sand Cost ($/TON)	**$60.00**	Binder GMBOND® (LBS/YR1)	946,688
Reclamation ($/TON)	$25.00	Binder GMBOND® (LBS/YR2+)	928,125
Sand Loss (% BOS reclamation)	**10.00%**	Scrap Cores % PUCB	5.00%
Scrap Rate (% of Shakeout)	0.00%	Scrap Cores % GMBOND®	0.10%
Casting Cost ($/CASTING)	$150.00	Reuse GMBOND® %	50.00%
Cost Breakdown PUCB YEAR 1		**Cost Breakdown PUCB YEAR 2**	
Sand ONE WEEK SUPPLY	$148,500	Sand ONE WEEK SUPPLY	$0
Binder	$4,637,655	Binder	$4,637,655
Reclamation	$3,757,050	Reclamation	$3,757,050
Sand Loss	$742,500	Sand Loss	$742,500
Scrap Cores	$231,833	Scrap Cores	$231,833
Scrap Castings	$0	Scrap Castings	$0
TOTAL	**$9,517,538**	TOTAL	**$9,369,038**

PUCB = Phenolic Urethane ColdBox®

Table 2-6 Cost Comparison GMBOND® vs. ColdBox® (ISOCURE®) - GM GEN IV Project

	Product	GMBOND®	Sub total	Total	ColdBox®	Sub total	Total
Cost of Reclamation	Pounds Sand/Casting	230			230		
	Total Sand Usage	57,500 tns		57,500 tns	57,500 tns		57,500 tns
	% Sand Loss						
	Reclaim	0%			0%		
	Disposal	10%	5750 tns	5750 tns	100%	57,500 tns	57,500 tns
	Basis for Binder Usage	63,250 tns		63,250 tns	57,500 tns		57,500 tns
	Sand Cost/Ton	$15-25		$948,750-1,581,250	$15-25		$862,2500-1,437,500
	Sand Disposal Cost/Ton	$15-30		$948,750-1,897,500	$15-30		$862,500-1,725,00
	Reclaim (GMBOND®) [1] Disposal Cost (ColdBox®)	$3		$189,750	$23		$1,322,500
Cost of Sand & Making Cores	Binder Cost	$2.75-3.25/lb.	$55-65/ton	$3,478,750-4,111,250	$0.75-0.85/lb	$15-17/ton	$862,500-977,500
	Amine TEA Cost	0		0	$0.85/lb	$17/ton	$977,500
	Description	GMBOND®			ColdBox®		
	Relative Tonnage for Cost Basis (Sand)	10-20%	6,325-12,650 tns	$948,750-1,581,250	100%	57,500 tns	$862,500-1,437,500
	% Sand Reclaimed	80-90 % cover core	50,600-57,150 tns	$151,800-170,775	100% disposal	0	$1,322,500
	Relative Tonnage For Cost Basis (Transportation)	10-20%	6,325-12,650	$948,750-1,897,500	100%	57,500 tns	$862,500-1,725,000
Savings Potential	Cost Range for GMBOND® vs. ColdBox®			$2,397,175-4,471,775			$4,887,500-6,440,00
	Cost Benefit for GMBOND® vs. ColdBox®			— $1,968,225-2,490,325 —			

[1] The cost for disposal of remaining GMBOND® material compared to ColdBox® is low because GMBOND® is crushed and recycled back into the system, whereas the residual ColdBox® product must be transported to landfill.

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APPENDIX A CORE WALL THICKNESS RESULTS FROM VARIOUS TEST PARAMETERS

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Total Purge Time	Tooling Temp Range	Binder Level	Moisture Level	Core Wall Thickness (inches)		
				Top of Core	Side Walls	Corner Walls
300	230-300	1%	2%	1.3	0.4	0.5
400	230-300	1%	2%	1.8	0.5	0.7
250	280-350	1%	2%	1.3	0.4	0.8
250	280-350	0.8%	2%	1.5	0.4	0.6
250	280-350	0.8%	1.8%	1.5	0.4	0.6
300	280-350	1%	2.3%	1.7	0.5	0.7
300	280-350	1%	2%	1.7	0.5	0.7
300	280-350	0.8%	2%	1.9	0.5	0.7
400	280-350	1%	2.3%	2.1	0.7	0.9

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APPENDIX B GMBOND® POWER USAGE PROFILE

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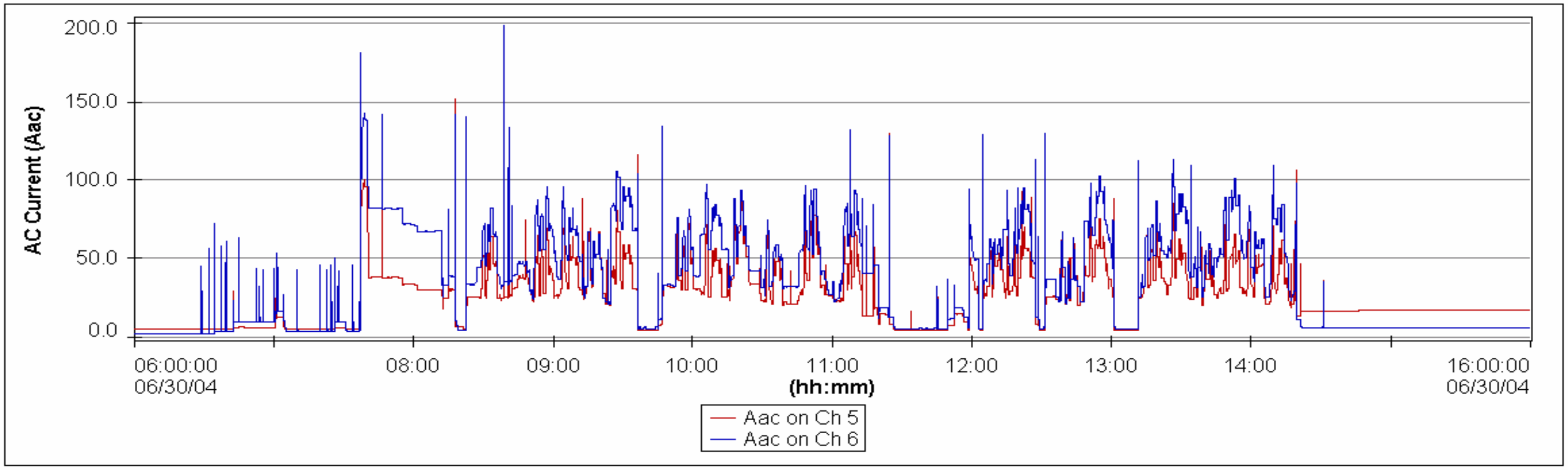
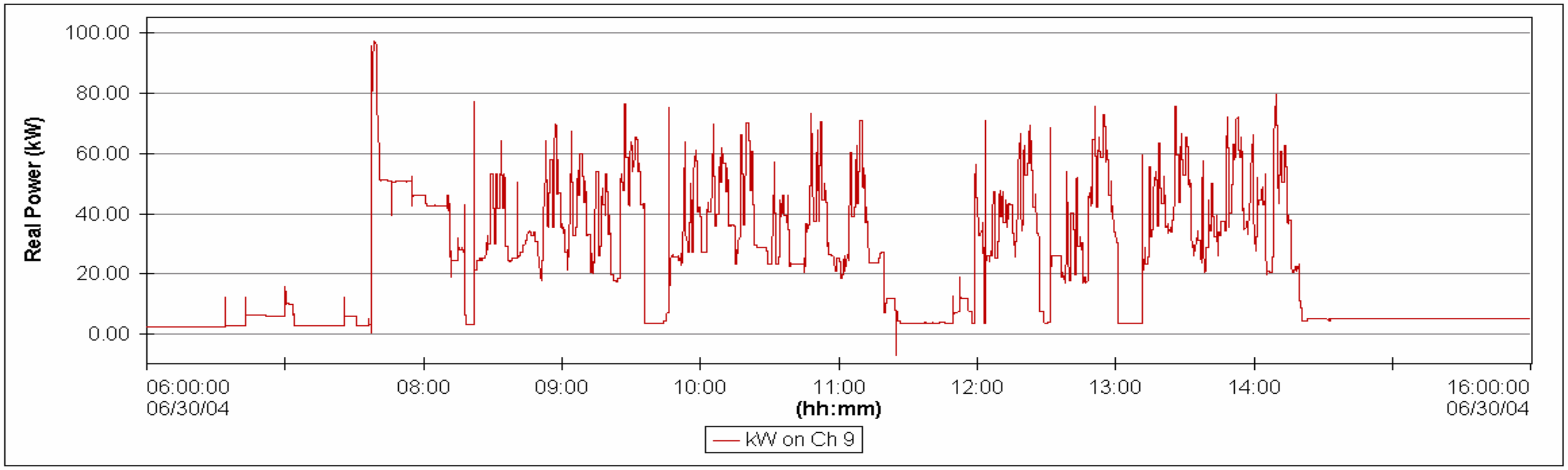
GMBOND® Power Usage Profile 30 June 2004 – 6 am to 4 pm





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APPENDIX C GLOSSARY

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Glossary

AFS	American Foundry Society
CARB	California Air Resources Board
CBA	Cost Benefit Analysis
CDVC	Casting Development and Validation Center
CERP	Casting Emissions Reduction Program
CRADA	Cooperative Research and Development Agreement
GEN IV	New generation V8 engine block
GM	General Motors
LOI	Loss on Ignition
PCS	Pour/Cooling/Shakeout
PUCB	Phenolic Urethane ColdBox®
R & D	Research and Development
TEA	Triethylamine
US EPA	United States Environmental Protection Agency