

Fall 1995

An Investigation into the Use of Expanded Polystyrene Patterns with the Loose-Sand, Vacuum Assisted Counter Gravitational Casting Process

John B. Vandersall
University of Northern Iowa

Let us know how access to this document benefits you

Copyright ©1995 John B. Vandersall

Follow this and additional works at: <https://scholarworks.uni.edu/grp>

Recommended Citation

Vandersall, John B., "An Investigation into the Use of Expanded Polystyrene Patterns with the Loose-Sand, Vacuum Assisted Counter Gravitational Casting Process" (1995). *Graduate Research Papers*. 3702.
<https://scholarworks.uni.edu/grp/3702>

This Open Access Graduate Research Paper is brought to you for free and open access by the Student Work at UNI ScholarWorks. It has been accepted for inclusion in Graduate Research Papers by an authorized administrator of UNI ScholarWorks. For more information, please contact scholarworks@uni.edu.

Offensive Materials Statement: Materials located in UNI ScholarWorks come from a broad range of sources and time periods. Some of these materials may contain offensive stereotypes, ideas, visuals, or language.

An Investigation into the Use of Expanded Polystyrene Patterns with the Loose-Sand, Vacuum Assisted Counter Gravitational Casting Process

**AN INVESTIGATION INTO THE USE OF EXPANDED POLYSTYRENE
PATTERNS WITH THE LOOSE-SAND, VACUUM ASSISTED
COUNTER GRAVITATIONAL CASTING PROCESS**

A Research Paper for Presentation
to the Graduate Faculty
of the
Department of Industrial Technology
University of Northern Iowa

In Partial fulfillment of the Requirements for
the Non-Thesis Master of Arts Degree

by
John B. Vandersall
Fall, 1995

Approved by: -

Dr. Yury Lerner (Advisor)

12-01-95
Date

Dr. Ahmed ElSawy
Graduate Faculty (Second Reader)

12-06-95
Date

Acknowledgments

I would like to express a sincere appreciation to Mr. Murry Patz and Mr. Archie Mathison, of Lost Foam Technologies for all of their assistance, and the donation of the patterns for this research. I acknowledge the assistance to Mr. Dixon Chandley, Director of the Metal Casting Technology, Inc. for selecting a topic of relevance pertaining to the LS Vac method of casting. I am grateful to Mrs. Terry DeLong and Ashland Chemical Co. for their technical support and the donation of an EPC refractory coating for this research. Thanks are also due to Drs Ahmed Elsayy and Yury Lerner for their assistance in the completion of this study and the technical report. Finally I would like to thank my colleagues of the Metal Casting Center who provided me with assistance during the progress of this research project.

TABLE OF CONTENTS

	PAGE
LIST OF FIGURES	vi
LIST OF TABLES	vii
CHAPTER I: INTRODUCTION	1
Statement of the Problem	1
Statement of the Purpose	2
Statement of the Need	3
Statement of the Research Questions	4
Delimitations	5
Statement of Procedure, Methodology, & Research Design.	7
Definition of Terms	9
CHAPTER II: LITERATURE REVIEW	13
EPC Process and Related Research	13
LS Vac Casting Process	16
CHAPTER III: METHODOLOGY	18
Observations and Collection of Data Procedures	20
Observation and Data analysis Procedures	20
CHAPTER IV: RESULTS & DISCUSSION	21
CHAPTER V: CONCLUSIONS & RECOMMENDATIONS	28
REFERENCES	33
APPENDIX A	35

LIST OF FIGURES

FIGURE NUMBER:	PAGE
1. LS Vac Castings (Group 5)	22
2. LS Vac Castings (Group 6)	23
3. LS Vac Castings (Group 7)	24
4. LS Vac Castings (Group 1)	24
5. LS Vac Castings (Group 2)	25
6. Conventional Pour Castings (Group 4)	26
7. Conventional Pour Castings (Group 8)	26
8. Edge Sand Burn-on (Group 7)	29
9. Drawing of EPS Pillow Block (Appendix A)	36
10. Drawing of EPS Pillow Block & Gating system (Appendix A)	37

LIST OF TABLES

TABLE:	PAGE
1. Casting Groups and there Parameters	19
2. Spectrometer Analysis	27
3. Furnace Charge Specifications (Appendix A)	38

1

CHAPTER I

INTRODUCTION

The use of expanded polystyrene (EPS) as a pattern material was first devised in 1958 when H.F. Shroyer was granted a patent for cavity less casting (U.S. Patent #2830343). Since then, the process has undergone many changes and modifications to optimize and simplify the process. Through all of the changes one thing has remained the same. Many still view this technology as a bright hope for the future of metal casting. The loose-sand, vacuum assisted, counter gravitational casting process (LS Vac) on the other hand is a relatively new technology. This process of vacuum assisted, counter gravitational casting is an improvement of the Counter gravity Low pressure Air melt Sand process (CLAS), both of which were patented by G. Dixon Chandley and Metal Casting Technology, Inc. This process still in the research phase of its life cycle shows promise in areas where other casting processes have failed.

Statement of the Problem

“Considered for years as a metal casting renegade, Expendable Pattern Casting (EPC) is believed by some to be tomorrows long-term casting future. Others, however, see it as an unproven headache-ridden process that makes the simple art of metal casting unnecessarily complex.” (Lessiter, 1994, p. 36). The complexity of this process has been largely due to the lack of knowledge surrounding the interaction of the metal front and the

dissipating polystyrene pattern.

Since the discovery of EPS as a pattern material, numerous applied research projects have been performed to gain a better understanding of the thermal breakdown characteristics of the material. As a result, knowledge of the reaction is much more thorough today than it was some thirty years ago, yet numerous other problems remain unsolved. Still EPC holds promise as a casting process of the future. The problem of this study is to identify if the loose-sand, vacuum assisted, counter gravitational casting method can be used to cast EPS patterns effectively.

Statement of the Purpose

Most of the recent EPC research has dealt with a variety of the common variables such as: the pattern coating, foam degradation, gating design, and pattern materials. The purpose of this study was to discover if the LS Vac casting process and its variables are applicable for use with EPS patterns.

The LS Vac casting process has shown promise in areas where other casting methods have failed. This fact teamed with its distinct process advantages make it an excellent process for research with the EPC process. Through this research I do not plan to perfect the combination of these two processes, yet simply find if further applied research involving them will be beneficial to the EPC process and foundry industry. The advantages of EPC can not only decrease production costs for the foundryman but can also reduce the manufacturing cost and increase the overall quality of the product to the consumer.

Statement of the Need

The EPC process although experiencing its share of criticism and short falls, still remains a promising casting option for the future. Lessiter (1994) quotes Jim Deppler, Saturn Corp. "The EPC process is undoubtedly the most environmentally friendly foundry operation of our time." When utilized to cast the proper class of castings, it can produce parts not easily castable by other methods and do so at a major cost savings.

There are several problems which have hindered the growth of this process. The first is the problems that occur as a result of contact between the rapidly advancing metal front and the EPS pattern which cannot dissipate quickly enough to avoid the molten metal. This can result in a variety of defects like: porosity, casting carburization, gas holes, cold shuts and incomplete fusion. More recent work has investigated the improvement of mold filling and fluidity in thin wall EPC castings (Proceedings of the 99th AFS Casting Congress, 1995) . It was found that pouring temperture has the greatest effect on the fluidity. Not only in the determination of time before solidification, but the casting temperture influences the nature of the pattern decomposition products, which also aid or hinder velocity.

These two factors are related very closely to each other in that they are hindered by one variable, the ability to evacuate all by products (gas and liquid) of the EPS pattern from the mold before it comes into contact with the advancing liquid metal front. This one variable is in turn controlled by several other variables; the metal temperature at casting, the coating permeability, the pattern density, the support sand permeability, and

the metallostatic head pressure. This system of independent variables is interrelated in such a way that it makes finding an optimum solution of all the variables a very long and tedious task. Then when another factor is added, such as the lack of reliable automatic pouring devices, the problems simply become more complicated. (Monroe, 1992).

The ongoing need for solutions to the above stated problems are the major reasons for this study. Lessiter (1994) quotes Piwonka, University of Alabama:

“EPC is now emerging as a capable process with unique capabilities, which will continue to fill a need for many casting applications. It’s full potential, however won’t be reached unless it is included in R&D programs investigating improvements in foundry technology, particularly clean casting and simulation engineering.”

Statement of Research Questions

The Research questions included in this study were proposed following a thorough review of recent literature and various related applied research projects. These questions will be answered based on the data and knowledge gained throughout the completion of this study. These questions and their answers can then be used by others planning to continue EPC research with the LS Vac process or any other casting method.

1. Will an applied vacuum level of 20" of HG and the upper of the two casting temperatures (2550°F) produce parts commonly displaying metal penetration and/or burn-on defects?
2. Will the casting quality between the six variations (10, 15, 20" HG at 2350 and 2550°F) of counter gravity cast parts show any difference in mold filling capability?

3. Does the previously established theory that increased casting temperatures lead to increased defect levels hold true with the results of this study?
4. Does very rapid mold filling, as associated with the LS Vac process fill the mold cavity before all of the EPS by products have had time to escape, thus leading to increased gas holes and porosity in the castings?
5. Will the lower casting temperature 2350°F cause problems with cold-shut in portions of the casting cavity for either of the casting methods?
6. Will the coarse, large grained sand used with the LS Vac process cause problems with surface quality or burn-on?

Delimitations

The large number of operating variables associated with both the EPC process and LS Vac casting can at times be difficult to predict and control. These independent operating variables may have a variety of affects on the casting qualities, as each casting will be unique in its own way. Some variables kept constant during this work could be the focus of future studies with these technologies.

Due to the large number of variables associated with both the technologies, this study was conducted in view of the following delimitations:

1. This research will only investigate one EPC pattern material the expanded polystyrene (EPS). Other materials such as PMMA (polymethyl methacrylate) which have shown promise as an alternative to EPS when casting ferrous materials were beyond the scope of this study.

2. There are a wide range of refractory EPC coatings available for a wide variety of applications and situations. This research will use a medium permeability ceramic coating , CERAMCOAT EP 9 510", produced by Ashland Chemical Co. For the purpose of this study, it is assumed that this casting is the ideal candidate for the current research parameters.
3. There are a variety of Vacuum levels that could be tested through this research. To limit the scope of this study, three different vacuum levels; 10, 15, and 20 inches of mercury will be tested.
4. The casting temperatures selected for this research (2350°F and 2550°F) are both, at or below, the recommended temperatures specified by the ASM Handbook (v15, p 232) for casting EPC gray iron castings. This is to test the mold filling capabilities of the LS Vac process with lower levels superheat.
5. A variety of research projects have been performed to determine the most appropriate method of gating. This research has failed to establish any general rules and regulations (Monroe, 1992). Previous study showed that top, side, and bottom gating locations produce castings of similar quality (Bailey, 1982). This research will apply a basic investment casting central sprue with four castings arrayed at 90° angles near the bottom-of the sprue (See Figures 9 & 10).
6. This project was delimited by two additional factors. Only thirty-two of the selected castings were available, thus limiting the scope of this study. These EPS patterns were expanded to a density of (1.5 pcf) which is a density level normally recommended for aluminum castings. (Arzt, Bralower, 1987)

Statement of Procedure, Methodology, & Research Design

This research work includes: 1) A thorough review of related literature, and 2) Application of this knowledge to a series of laboratory experiments. The data and observations gained as a result of the research will then be used to answer the research questions and to provide basis for continued research in this or related areas.

This research will evaluate the effects of the applied vacuum level in conjunction with the casting temperature and molding media on the surface quality of the produced EPS gray iron castings. As a basis for this study, eight castings from identical expanded polystyrene patterns will be cast in the traditional pouring method. These castings and the data from their cast will provide a basis for comparison to the LS Vac counter gravity castings. The variables that will be manipulated with the LS Vac castings include: 1) The applied vacuum level (10, 15, 20 inches of Hg respectively) and 2) The casting temperature (2350°F and 2550°F).

The procedure for the research includes the preparation of the EPS patterns for casting by assembling, gluing, and coating with a ceramic slurry (Ballmann, 1988). Once the patterns have air dried for approximately 24 hours, they are ready to cast. Two of the EPC clusters are loaded into 14 inch diameter metal tubs that are then filled with silica sand and vibrated to reach maximum density. These two clusters are then cast by conventional methods (from a ladle down into the cavity), one at 2350°F and the other at 2550°F. The remaining six clusters are all cast by the LS Vac method of counter

gravitational casting. Each cluster is cast in one of the six combinations of the variables; temperatures of 2350°F and 2550°F, and at the vacuum levels of 10, 15, 20 inches of Hg. This setup will yield four castings for each combination of the variables and four baseline castings from each proposed pouring temperature.

The resulting castings will be allowed to cool to room temperature and then the surface quality of the castings will be evaluated for various defects; mold collapse, wash erosion, burn-on, gas blows, and cold shut. Once the castings have been evaluated for these defects they will be cleaned and examined under a microscope in an attempt to determine the cause of any surface defects. The observations will then be analyzed to determine if there are any relationships between the casting temperature, vacuum level, and the casting media.

Time Schedule for Research Project

<u>TASK TO BE COMPLETED</u>	<u>COMPLETION DATE</u>
• Complete Literature Review	September 12
• Complete Review of Literature	September 19
• Complete Rough draft of proposal	October 13
• Draft of entire paper due	October 24
• Complete revisions on Proposal	November 3
• Perform Casting Trials & analyze castings	November 10
• Complete revisions on Remainder of paper	November 17
• Hand in Final copy of Research Paper	November 28
• Graduate office notified of Research Paper Acceptance	December 1

Definition of Terms

Many of the terms in this research paper are common to personnel who are actively involved in the study of metal casting technologies. But to others the terms may have no meaning at all or may be misinterpreted and occasionally not agreed upon by knowledgeable persons. The following terms are defined to clarify their use in the context of this research and report.

Automatic Pouring Devices: This term refers to pouring devices that provide consistent and predictable pouring results cast after cast.

Cavity less Casting: The original name given to the expendable pattern casting process as created by H.F. Shroyer in 1958. See *Expendable Pattern Casting (EPC)*

Clean Casting Technology: A technological process or product that assists in achieving a cleaner more homogeneous metallurgical casting quality (free of macro and micro inclusions)

Cold Shut: A discontinuity that appears on the surface of cast metal as a result of two streams of liquid metal meeting and failing to unite (ASM Handbook v15, 1988, p.3).

Conventional Pouring Methods: this refers to the act of pouring molten metal from a crucible or ladle down (with the aid of gravity) into the casting cavity.

Counter Gravity Low Pressure Air Melt Sand molding (CLAS): This is the original counter gravity casting process to use resin bonded sand molds. This process inserted the end of the resin bonded mold directly into the furnace, then the atmospheric

pressure outside the canister in response to the vacuum created in the canister and mold cavity pushes down on the metal bath outside the canister forcing the metal quickly but smoothly to flow into the casting cavities.

Environmentally Friendly: This term is used to describe a process or product that is harmless or nearly harmless to our environment. That is it does not present any major health risks to anyone, and does not present any long-term pollution hazards to the environment.

Expanded Polystyrene (EPS): EPS is derived from the combination of benzene and ethylene. These beads then pass a pre-expansion step which utilizes a blowing agent to prepare the beads for molding. Then after being blown into a mold, a steam cycle then causes the beads to expand and fuse together.

Expendable Pattern Casting (EPC): Expanded thermoplastic foam patterns are surrounded by unbonded sand, and then vaporized during pouring of the molten metal. The resulting casting is an exact replica of the foam pattern it vaporized. This process is known by a number of different names: Lost Foam, Evaporative Pattern Casting, Styrocast, Styropour, Foamcast, Cavity less casting, Policast, Foam Vaporization Casting.

Fluidity: The ability of liquid metal to flow into and fill a mold or die cavity. (ASM Handbook v15, 1988, p.6)

Full Mold Process: Molten metal is poured onto a solid expanded polystyrene (EPS)

unbonded sand (Behi, Gallois, & Panchal, 1987).

Gating: (generic term) the entire system of adjoining channels that direct metal into the mold cavity.

Gray Iron: (See Table 3 for charge specifications) Cast Iron that contains a relatively large percentage of the carbon present in the form of flake graphite (ASM Handbook v15, 1988, p. 6)

Investment Casting Central Sprue: (generic term) a single central sprue which is used in various casting processes (particularly Investment Casting) to supply molten metal to a number of castings which are attached to the sprue at various points (casting tree/cluster).

Lamellar Flow: Used to describe the smooth and unturbulent flow of a liquid.

Loose Sand Vacuum Casting (LS Vac): This process is a refinement of an earlier technology called CLAS, for Countergravity Low-pressure Air melt Sand molding, applies countergravity casting techniques to the resin-bonded sand molding process (Girolimon, 1995)

Lustrous Carbon: A defect which occurs in ferrous EPS castings. This defect is caused when the pattern is forced to vaporize too rapidly, leaving behind in the molding cavity plastic residue. When the metal comes in contact with this residue it forms surface areas of particularly high carbon levels (Monroe, 1992).

Misrun: An irregularity of the casting surface caused by incomplete filling of the mold due to low pouring temperatures, gas back pressure from inadequate venting of the

mold, and inadequate gating (ASM Handbook v15, 1988, p. 8).

Permeability: The degree to which a porous body or aggregate will allow gases or liquids to pass through (Monroe, 1992, p. 115).

Polymethylmethacrylate (PMMA): This experimental expandable resin is uniquely suited for gray iron, ductile iron, and low carbon steels due to the low carbon pick-up experienced as an effect of the pattern decomposition.

Porosity: A characteristic of being porous, with voids or pores resulting from entrapped air or shrinkage in a casting (ASM Handbook v 15, 1988, p.9).

Refractory Coating: Suspensions of specially selected materials in a liquid carrier that, when applied to a surface and the liquid is removed, leave a covering of the special material, which will have a desirable effect on the casting (Monroe, 1992, p. 115).

Silica Sand: a readily available, inexpensive sand composed almost entirely of silica (SiO_2) in the form of Quartz.

CHAPTER II

LITERATURE REVIEW

EPC Process and Related Research

The use of expanded polystyrene as a pattern material originated on April 15, 1958 when H.F. Shroyer was granted a patent (patent # 2,830,343) for what was then termed cavity less casting (ASM Handbook v15, 1988). The next significant breakthrough in EPC came in 1964 when T.R. Smith was granted a patent (patent # 3,157,924) for a variation of Shroyer's process using loose, unbonded sand instead of green sand as the casting media (ASM Handbook v15; 1988). Upon expiration of Smith's patent the use of and research in the EPC process grew at a dramatic rate.

The renewed interest in the process although pursued by many, quickly faded as knowledge of the processes many variables lacked. The lack of early success was met by a variety of opinions and responses. Some felt from the beginning that this process was more hassle than it was worth, while others knew that applied research would answer many of the problems that had prevented its success. A variety of applied research projects set out to uncover the mysteries of the EPC process. Since then, many of the unknown operating variables of the EPC process have been solved; yet others still prevent its acceptance as a successful casting process today. Still many hold hope that continued research will find the key to improving its outlook in the near future.

The results of numerous past research projects have clarified questions concerning

general casting parameters and processes. Many studies have been performed to establish a set of guidelines for gating EPC patterns. Most of the results have been identical in that no major difference in casting quality was noticed when bottom, side, or top gating practices were followed (Bailey, 1982). Other research projects studied topics such as: molding media, refractory coating permeability, pattern materials, and pattern density have all produced results that are case sensitive (Askeland, Tseng, 1991). They depend upon a number of other variables in the casting procedure such as metal being poured, the use or lack of a vacuum, and surface quality desired.

Recent research has primarily dealt with the understanding and correlation of a much more complicated set of related variables. The majority of problems with EPC castings today involve problems attributable to the relationship between the vaporizing EPC pattern and the rapid moving metal front. The relationship between these two actions is very complicated and tough to control. It is for this reason that the majority of all EPC research has in some way directly or indirectly dealt with this topic. There were three variables which play a major role in this relationship. They are the casting temperature, metallostatic pressure, and coating permeability (Askeland, Tseng, 1991).

The three above listed variables are interrelated in a system that is hard to perfect once, much less on a production basis. The casting temperature with EPC must be much more strictly controlled than with other casting methods. When casting temperatures are kept low, less gas is produced by the vaporization of the pattern. Yet the lack of superheat combined with the quenching affect that contact with the pattern material often

cause problems with cold shuts. The next few paragraphs will show the relationships between these three variables. EPC patterns undergo an endothermic reaction during vaporization greatly reducing the metal front temperature (and fluidity) thus decreasing the mold filling capabilities (Askeland, Tseng, 1991). When casting temperatures are increased, the evolution of gases increases as well causing increased problems with porosity and gas holes or blows. The higher temperatures (more superheat) provide increased fluidity and thus increase mold fill-out.

The permeability of the refractory coating is another important variable in the casting process. Recent studies have shown that while high coating permeability levels allow more vaporization by products to evacuate the molding cavity, the occurrence of burn-in / burn-on defects increases substantially (Caironi, Gorla, Serramoglia, Tosi, 1986). When a vacuum is used during casting, a high permeability level does not provide an acceptable pressure drop across the coating leading to problems with mold collapse (Ashton, Sharman, Brookes, 1984). A lower permeability coating increases the pressure drop across the coating layer providing increased support to the cavity wall (Ashton et al., 1984). The lower permeability levels retard the escape rate of the gas and severely limit the escape of liquid by products leading to an increased occurrence of porosity and lustrous carbon defects.

Metallostatic head pressure is the final variable that Askeland & Tseng (1991) note of importance to the fluidity and mold fill-out capabilities of a EPC casting system. Their studies have shown that this variable is controlled to a large extent by the type of

decomposition materials that are produced by the vaporizing EPC pattern. The decomposition materials are in turn determined by the casting temperature, the pattern material, and the pattern density. When the decomposition materials are primarily liquid in nature, the metal front velocity increases. When the material byproducts are gaseous in form, the increased pressure from the gas decreases the metal front velocity.

1 The Replicast FM or Full Mold process was developed by the Steel Castings Research and Trade Association, Sheffield, England. This process is similar to the conventional EPC casting process with the only exception being that a vacuum is applied to the molding flask. The use of the vacuum has allowed the use of higher density patterns which provide improved pattern strength and improved surface finishes. Additional advantages that were experienced with the use of a vacuum include much higher cavity wall strengths which withstand very high metallostatic head pressures thus significantly reduce mold collapse defects (Ashton et al., 1984).

LS Vac Casting Process

Due to the fact that the LS Vac process is relatively new, the amount of literature on background information and prior research performed is limited. This process has been shown to exhibit the same process advantages that many of the other counter gravity, vacuum assisted casting methods have shown. The Loose Sand, counter gravitational, vacuum assisted casting method is a process which was created and patented by G. Dixon Chandley and the Metal Casting Technology, Inc. The process was created as an

improvement on an older counter gravity casting process also created by Chandley called CLAS or Countergravity Low-pressure Air melt Sand molding (Girolimon, 1995). These processes are designed around the central principal that when a vacuum is created in the casting cavity (and canister) and then immersed below the surface of the molten metal, the atmospheric pressure on the remainder of the metal bath will force the metal up into the casting cavity. This provides a relatively rapid non-turbulent, fill of the mold cavity.

Other advantages of this process include:

- Cleaner metal with less slag and nonmetallic inclusions
- Lower metal and mold temperatures required
- Finer grain structure
- Improved mold fill-out, especially in thin sections
- Increased casting efficiency

(Girolimon, 1995)

CHAPTER III

METHODOLOGY

Results of this experimental work, data collected and observations gained will contribute to the unknown variables discussed in the research questions section and provide suggestions for future. As mentioned before, the purpose of this study was to discover if the LS Vac casting process and its variables are applicable for use with EPS patterns. The experimental study, which will attempt to prove or disprove this statement, will research the combination of these processes with three controlled variables. The three variables used in this study are the vacuum level, the casting temperature, and the molding media. These castings will then be compared as a basis to castings poured in the traditional method.

Each of the eight casting cluster trees will be assembled first, in identical manners. Each cluster will consist of a square central casting sprue and four castings branched off at 90° angles to each others. The castings are then attached to the casting sprue with a low temperature glue. Once cooled and stable the patterns will then be covered with the refractory coating (Ceramcoat EP9510) and allowed to air dry for 24 hours. This concludes the steps necessary to prepare the patterns for casting.

A metal cylindrical drum approximately 14" in diameter is used as a traditional casting flask. The two gravity pour casting sprues are separately placed in this canister, backed with a 60 GFN Silica sand, and poured following the proposed guidelines (ASM

Handbook v15, 1988). After a base of sand is placed in the bottom of the canister, the pattern is placed in position. Additional sand is then poured around the patterns and sprue vibrating the canister at various intervals to prevent the disformation of the patterns prior to casting. Upon the completion of the filling and support of the castings they are prepared for casting. Gray iron is then poured into the first mold cavity when the temperature is 2550°F. The second mold will be poured when the metal temperature drops to 2350°F. These castings will be allowed to cool to room temperature, dumped out and left in their as cast condition for comparison to the remainder of the sample castings.

The six remaining clusters will be cast with the LS Vac casting system and will utilize the below listed variables controlling the cast

Cast Group#	Casting Temperature	Casting Vacuum ("Hg)
1	2350°F	10
2	2350°F	15
3	2350°F	20
4	2350°F	Conventional Pour
5	2550°F	10
6	2550°F	15
7	2550°F	20
8	2550oF	Conventional Pour

Table 1. Casting Groups and there parameters

These castings will also be kept in their as cast condition for comparison with the baseline castings.

Observations and Collection of Data Procedures

Each casting will first be observed for a variety of identifiable surface defects and for any major differences in surface quality. These defects are as follows; partial / full mold collapse, wash erosion, gas holes/ blows, burn-on, and penetration. Then all of the casting clusters will be cleaned in a rotary table shot-blast machine. Once cleaned, they will be visually re-examined for the above listed defects and their surface quality again. Each casting will then be examined at 20X magnification under a microscope to more closely examine the surface quality of the casting and any surface defects that may have occurred.

Data Analysis Procedures

The observations and data obtained from this study will then be analyzed to determine the compatibility of the two processes. The observations of the various defects will be evaluated based on knowledge gained through the review of literature to determine the probable causes of each.

CHAPTER IV

RESULTS & DISCUSSION

The following is the data and results from the thirty-two experimental castings poured. Included in this data are photographs of the resulting castings from each of the eight casts. Spectrometer analysis of the metal at each cast was taken for metallurgical background if required. These results will be analyzed, then conclusions and recommendations will be deducted from the analysis.

Twenty-eight castings were obtained from the thirty-two parts attempted. The four parts that did not successfully yield castings were cast at 2350°F and with 20 inches of vacuum. The patterns and ingates for these castings were the only thing remaining from the original pattern following inspection. The point where the ingates attached to the central sprue was impregnated with numerous sand particles, and a clump of metal coated sand was the only metal which was yielded from the mold remnants. The temperature at casting was 2360°F and at the set casting dwell time of 15 seconds.

The remainder of the parts cast with the LS Vac process were successful. Arranged below are the photographs of the castings and a description of their physical appearance.

Group 5 (2550°F, 10" Hg):

These casting seen below in Fig. 1 were cast under the above parameters with the LS Vac system. The surface finish of these castings was rough and showed signs of both

inclusions and burn-in / burn-on. All of the castings had minor burn-in problems with the coarse grain sand, but the location varied from casting to casting. Three of the four castings in this group showed serious problems with inclusions near the ingate. Upon further review under a microscope at a low magnification of 20X the inclusions were spotted with some of the refractory coating.

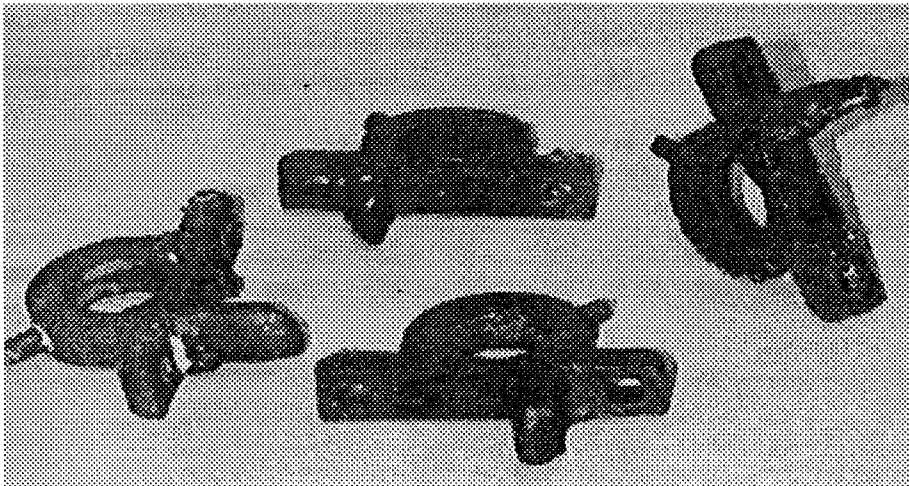


Fig. 1 LS Vac Castings (2547°F, 10"Hg)

Group 6 (2550°F, 15"Hg):

Figure 2 shows this group of castings produced similar results to those in group 2 which were cast at the same vacuum level. Sand burn-on was once again a problem, but did not seem to occur in any one particular or in any patterns. The problem with non-metallic inclusions was evident again, but not to the degree that was found in group 7. The inclusions occurred primarily in two of the four castings, while the other two were almost void of any inclusions at all.



Fig. 2 LS Vac Castings (2538°F, 15"Hg)

Group 7 (2550°F, 20"Hg):

The castings shown in the photograph, Fig. 3 were by far the worst of any of the castings produced. Problems with non-metallic inclusion once again were evident and scattered throughout the casting. Sand burn-on was the major problem with these finished castings. The sand was mainly a problem on the arched section of the casting and along the edges of the casting. After reviewing the castings under the microscope, it was evident that the grains were adhered to the surface by the cast iron that escaped the refractory coating and solidified in the sand support. For a close up image of one of the castings refer to Figure 8, page 29.

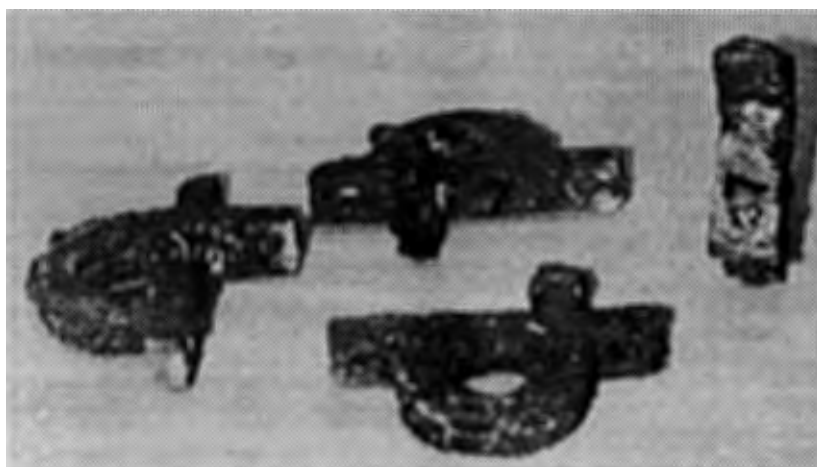


Fig. 3 LS Vac Castings (2549°F, 20"Hg)

Group 1 (2350°F, 10"Hg):

The photograph of castings seen in Fig. 4 showed the least problems with sand burn-on when compared to the other CG castings. Two of the castings showed a little burn-on on the edges of the arched section and some on the inner walls of the circular hole feature. Inclusions were found in all of the castings to varied degrees and in scattered locations.



Fig. 4 LS Vac Castings (2365°F, 10"Hg)

Group 2 (2350°F, 15"Hg):

Figure 5 photograph shows the casting obtained with the above listed parameters. Following cleaning, microscopic inspection revealed a greater amount of refractory entrapped in the inclusions than was evident in groups 1 or 5 which used 10" Hg. The amount of inclusions found in the castings increased as well. The sand burn-on problem was at approximately the same scale as the castings in group 6, as were the inclusion defects.



Fig. 5 LS Vac Castings (2380°F, 15"Hg)

Groups 4 & 8 (2350°F & 2550°F, conventional pouring):

These two groups which were the basis for the study yielded the best castings. Sand burn-on (Silica sand) with both groups was almost non-existent. Inclusion defects over 1 mm in diameter did not occur. After examining the surface under 20X, there wasn't any sign of refractory coating remaining on the surface. The surface structure was an exact duplicate of the EPS pattern replaced.



Fig. 6 Conventional Pour (2385°F)



Fig. 7 Conventional Pour (2571°F)

	Grp 1	Grp 2	Grp 3	Grp 4	Grp 5	Grp 6	Grp 7	Grp 8
% C	3.55	3.58	3.57	3.58	3.58	3.53	3.39	3.35
% Si	1.769	1.770	1.718	1.742	1.797	2.433	2.464	2.425
% Mn	0.196	0.192	0.186	0.181	0.197	0.208	0.207	0.202
% P	0.015	0.014	0.014	0.014	0.014	0.015	0.016	0.014
% S	0.003	0.003	0.005	0.005	0.006	0.007	0.007	0.007
% Ni	0.062	0.065	0.065	0.066	0.063	0.068	0.065	0.064
% Cr	0.042	0.043	0.042	0.042	0.044	0.046	0.047	0.044
% Cu	0.151	0.156	0.151	0.149	0.160	0.164	0.160	0.150
% Al	0.004	0.003	0.000	-0.004	0.004	0.011	0.004	0.000
% Ti	0.014	0.015	0.014	0.013	0.014	0.014	0.014	0.014
% Sn	0.003	0.003	0.003	0.003	0.003	0.004	0.003	0.003
% V	0.012	0.013	0.013	0.012	0.015	0.014	0.014	0.014

Table 2. Spectrometer Analysis

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

The compatibility of the LS Vac process and its variables with EPS patterns was evaluated in this study by the visible appearance and surface quality of the casting produced. The castings produced were evaluated by eye and under a microscope at 20X power. Through this analysis of surface quality and produced defects, the research questions will be answered and speculation for continued research in this area will be provided. The conclusions of this study will be broken down into three parts: vacuum, temperature, and molding media effects on the castings surface quality.

Vacuum levels in this study played the largest role in the castings surface quality. The most noticeable areas that showed variation with changing vacuum levels were burn-on problems with sand and the refractory coating. As the vacuum levels increased the amount and severity of sand & refractory coating burn on problems increased as well. The castings produced at vacuum levels of 10 and 15 had some problems with sand burn-on in a much more sporadic pattern, while those cast at 20 inches of mercury had serious problems along the outer edges and on the inside wall of the circular feature (See Figure 8, page 29). Similar observations were made with the refractory coating, increased vacuum levels led to increased burn-on defects.



Fig 8 Edge Sand Burn-on (Group 7)

The castings showed little if no difference based purely on the casting temperature. Groups of similar vacuum levels and different casting temperature produced little or no observable difference or trend of the proposed defects or surface quality. Based upon these findings, the two temperature levels did not pose enough of an extreme, or difference to produce any noticeable variations.

The LS Vac process of metal casting traditionally uses a very coarse and large grained sand for the back-up of the casting mold in use (no-bake sand mold, investment casting shells, shell molds, etc...). This sand appears to have served the two primary purposes it is used for, allow the escape of the gases from the pattern and provide dimensional support for the molten casting. The problems with sand burn-on experienced are most likely a result of too much pressure on the metal forcing it through the coating. The inclusion defects on the other hand could have been caused by the irregular and rough grains of this sand.

The 60 GFN silica sand used with the traditionally poured castings is a much more

consistent in grain shape and size. These factors could provide a much more stable support system for the refractory coating. The odd shaped and sized sand used with the LS Vac unit may have shifted during the casting process causing the inclusions of sand and coating.

All of the traditionally poured patterns produced acceptable parts. These castings showed no detrimental inclusion defects and had only a minimum of sand burn-on problems. The American Foundrymen Society suggests pouring gray iron EPS patterns between the temperatures of 2500°F and 2650°F. The parts poured at 2350°F were cast successfully with a significantly reduced level of superheat. This success appears to be due mainly in part to a central sprue that was much larger than needed for the parts being cast. While the parts cast at 2550°F turned out as expected under these variables.

The gating system utilized in this system did not follow any of the proposed ratios and guidelines commonly followed in the metal casting industry. This could be an underlying cause in one or both of the defect problems which were experienced in this study.

Recommendations:

There are several different solutions to the two major problems experienced in this study. The first problem I will address is that of sand and coating burn-on. The following list of possible solutions are listed in no particular order.

1. If the same coating is used, try the addition of another layer after the first has fully dried. This should seal any cracks while providing additional support all over the

casting.

2. Try the use of a lower permeability refractory coating
3. If neither of the above solutions work, the vacuum level may have to be reduced below 10 inches of mercury.

The second major problem faced with this study was that of non-metallic inclusions at various locations on all of the LS Vac castings. Listed below are possible solutions for this problem:

1. A 40 or 50 GFN silica sand would provide a more stable support for the molten metal. Anything smaller in grainsize than 50 would present problems with the filtration system of the LS Vac unit.
2. Vibrate the canister more often to reduce the number of voids in the support sand. This should reduce the chance of sand shifts when the vacuum is engaged, and when the pattern dissipates.

My final recommendations for future studies involving EPC and the LS Vac unit are:

1. Coat the patterns with two layers of the chosen refractory coating or try using a lower permeability coating with only one coating.
2. Use a 50 GFN silica sand to test for inclusion problems with this back up media.
3. Vibrate the LS Vac canister constantly while loading sand immediately around the pattern, then at common intervals (every 10 to 15 seconds) while filling in the top support sand.

4. A vacuum level of 20" Hg is far more than is required to draw the EPS castings. I would suggest trying a lower vacuum level, possibly 7 or 8 inches of mercury.
5. Further test the extremes of casting temperature, attempting to show a difference (if there is one) between casting very hot and cold with EPC and the LS Vac process.
6. For future studies the proper gating ratios and design should be utilized to exclude this as a possible factor.

Through this research, several similarities and differences have been uncovered between the two processes. Future research should not only continue the research of the basic process compatibilities but should explore the interior structure of the casting produced through this combination. What effect does the vacuum and casting temperature have on the subsurface microstructure and defect level? Are these castings produced with the LS Vac process more sound internally than those cast traditionally? These and numerous other questions for future research can be drawn from the castings and data obtained in this study.

The successes and failures of this study will prove integral when additional research is conducted with these two processes. The failures of this study provide questions for future research, while the successes provide guidelines. The combination of these two processes still appears to be relevant and worth additional research. If and when this research is conducted, it may provide the solutions that will guarantee the future of the metal casting industry.

REFERENCES

- Arzt, A.M., Bralower, P.M. (1987). Questions about EPC Vaporize With Proper Practice. Modern Casting, 77, 21-24.
- Ashton, M.C., Sharman, S.G., Brookes, A.J. (1984). The Replicast FM (Full Mold) and CS (Ceramic Shell) Process. AFS Transactions, (84-22), 271-280.
- Askeland, D.R., & Tseng, C.H. (1991). A Study of selected Process Parameters for the Evaporative Pattern Casting Process. AFS Transactions, (91-134), 455-463.
- ASM Handbook Committee., (1988). ASM Handbook, v15 Casting, 9th Edition, ASM International.
- Ballmann, R.B., (1988). Assembly and Coating of Polystyrene Foam Patterns for the Evaporative Pattern Casting Process. AFS Transactions, (88 - 77), 465 - 470.
- Caironi, G., Gorla, C.A., Serramologia, G., Tosi G., (1986). Coating Permeability: A Critical Parameter of the Evaporative Pattern Process. AFS Transactions, (86 - 101) , 589 - 600.
- Easwaran, J. (1993). Research Advances EPC Process. Modern Casting, 83, 52.
- Flemings, M.C. (1987). Foam Vaporization Casting. AFS Transactions, (87-07), 665-671. -
- Gallois, B., Behi, M., Panchal, J.M. (1987). Polystyrene in the Full-Mold Casting of Grey Iron. AFS Transactions, (87-87), 579-590.

Girolimon, G. (Aug 24, 1995). Profile: Hitchiner Manufacturing Co., Inc. [World Wide Web], Available: <http://www.hitchiner.com/himco/Profile.html>.

Lessiter, M.J. (January 1994). Expendable Pattern Casting: State of the Process. Modern Casting, 84, 36-38.

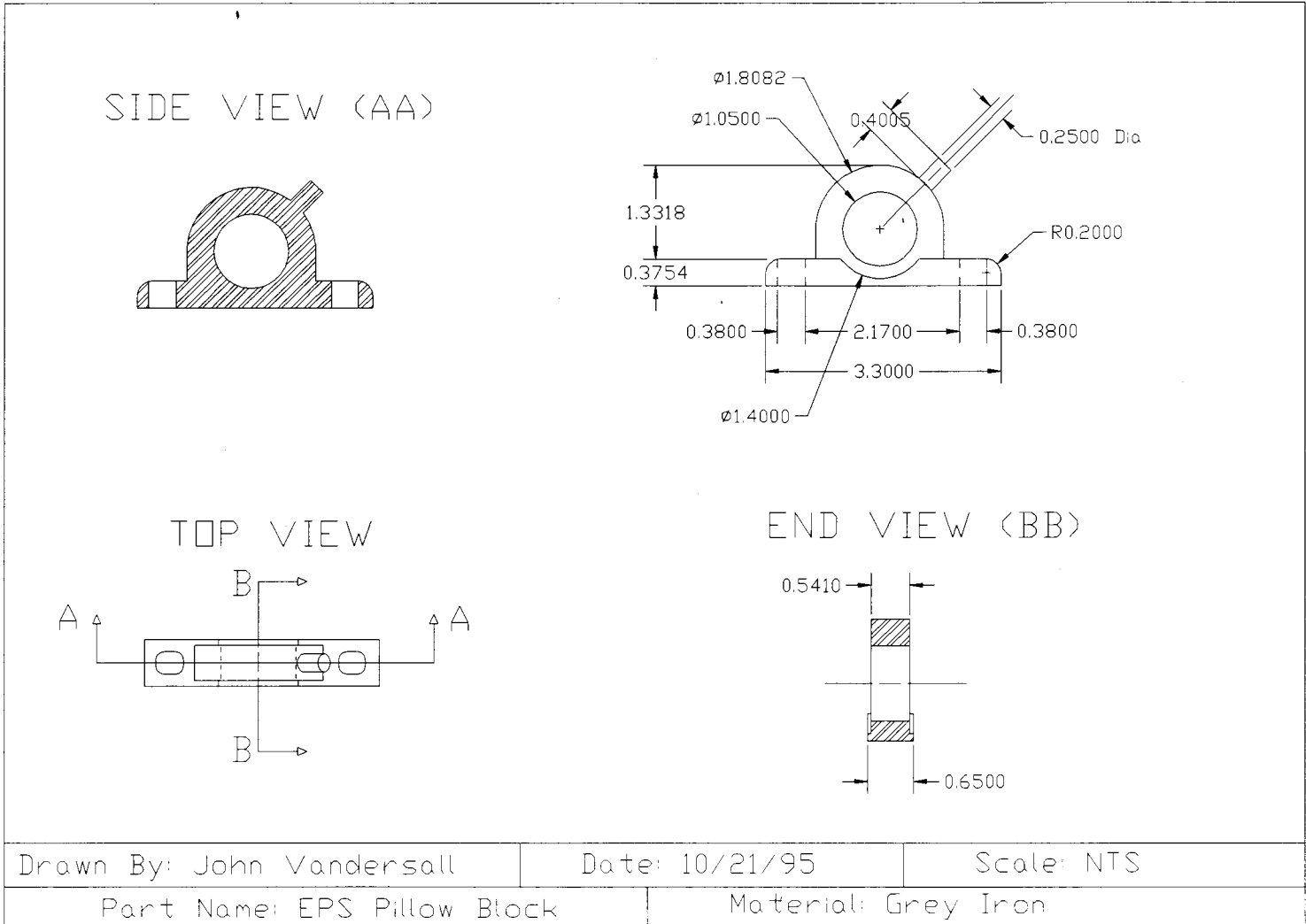
Monroe, R.W. (1992). Expendable Pattern Casting. Des Plaines, IL: American Foundrymen's Society, Inc.

Proceedings of the 98th AFS Casting Congress (June, 1994). Mold Filling Plays Key Role in Quality. Modern Casting, 84, 35-37.

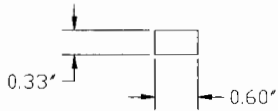
Twarog, D.L. (1993). EPC Research Reinforces Benefits. Modern Casting, 83, 36.

APPENDIX A

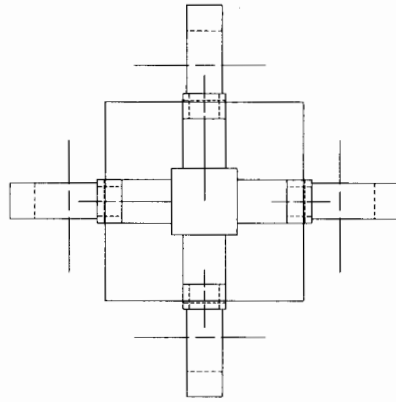
Figure 9 Drawing of EPS Pillowblock



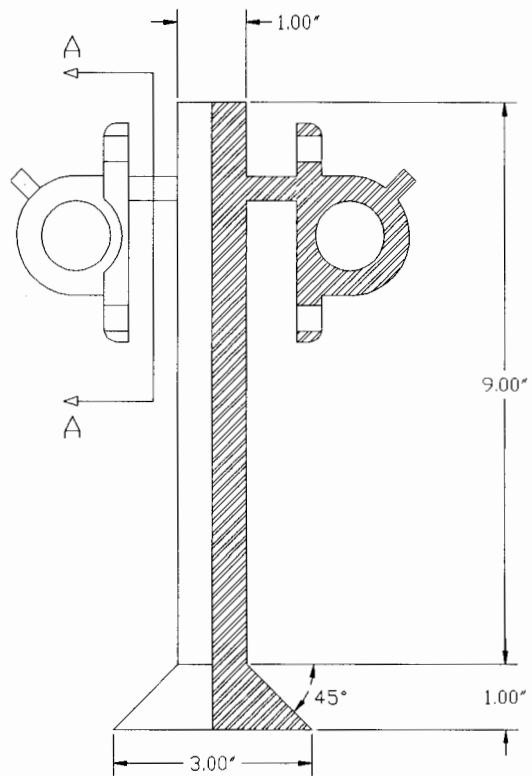
Section AA



Top View



Side View (Half Section)



Drawn By: John Vandersall	Date: 10/21/95	Scale: NTS
Part Name: EPS Pillow Block & Gating	Material: Grey Iron	

Fig. 10 Drawing of EPS Pillow Block & Gating System

Material	Additions in pounds
Pig Iron	137.5
Ductile Iron Returns	87.5
Steel	25.0
FeSi (Furnace additions)	5.5
Carbon Raiser	0.5

Table 3: Furnace Charge Specifications (250 lb Heat)

Desired melt chemistry for this project was:

3.58% C

2.05% Si

LOST FOAM TECHNOLOGIES INC., DIVISION OF:
 Kohler General Corp
 100 CLARK STREET
 P.O. BOX 902
 SHEBOYGAN FALLS, WI 53085-0902

* INVOICE *		
Invoice date	Invoice no.	Page
10/11/95	038152	1

Order#	Order date	Customer Sls	PO#	Terms	Ship-via	Pkgs
032959	10/11/95	799988	ALM N/A	NO CHARGE	UPS	1

Bill to: UNIVERSITY N IOWA
 INDUSTRIAL TECH CENTER
 CEDAR FALLS, IA 50614-0178
 Attn: Accounts Payable

Ship to: UNIVERSITY N IOWA
 INDUSTRIAL TECH CENTER
 CEDAR FALLS, IA 50614-0178

Line	Quantity	Item Description	List-pr Unit-pr	Dscnt Ref	Ext-amount
1	32.00	PILLOW BLOCK FOAMS- 1.5 PCF		None	.00
2	8.00	CROSS ARM GATING- 1.5 PCF		None	.00

ATTN: JOHN VANDERSOLL

REMIT TO:
 LOST FOAM TECHNOLOGIES
 P. O. BOX 902
 SHEBOYGAN FALLS, WI 53085

Sale amount	.00
Sales tax	.00
Total	.00
Balance due	.00