

# Behavior of Generated Gas in Lost Foam Casting

M. Khodai, S. M. H. Mirbagheri

**Abstract**—In the Lost Foam Casting process, melting point temperature of metal, as well as volume and rate of the foam degradation have significant effect on the mold filling pattern. Therefore, gas generation capacity and gas gap length are two important parameters for modeling of mold filling time of the lost foam casting processes. In this paper, the gas gap length at the liquid-foam interface for a low melting point (aluminum) alloy and a high melting point (Carbon-steel) alloy are investigated by the photography technique. Results of the photography technique indicated, that the gas gap length and the mold filling time are increased with increased coating thickness and density of the foam. The Gas gap lengths measured in aluminum and Carbon-steel, depend on the foam density, and were approximately 4-5 and 25-60 mm, respectively. By using a new system, the gas generation capacity for the aluminum and steel was measured. The gas generation capacity measurements indicated that gas generation in the Aluminum and Carbon-steel lost foam casting was about 50 CC/g and 3200 CC/g polystyrene, respectively.

**Keywords**—gas gap, lost foam casting, photography technique.

## I. INTRODUCTION

DOCUMENT is a template The lost foam casting process utilizes polymeric foam pattern for the production of metallic components. Pattern of the desired shape and dimension are coated with a refractory coating, then dried and embedded in unbonded sand. Molten metal is poured directly on the pattern; the foam undergoes thermal degradation and is replaced by the liquid metal. Expanded polystyrene (EPS) is the most common polymer used in commercial practice. During the mold filling of the lost foam casting process, the refractory coating has many functions to perform. The coating must permit the escape of gases from the mold cavity. The gas removal is necessary to fill the mold cavity so as to prevent the void area. The refractory coating must prevent the collapse of dry sand into the mold cavity during the mold filling.

Refractory coating selection mainly depends on gas generation rate in the mold and the gas gap length. For instance with increasing gas generation rate in the mold, the coating permeability must be increased and with increasing gas gap length, the coating strength must be increase to prevent the collapse of dry sand into the mold cavity.

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Shivkumar et al. used photography technique in lost foam casting for various materials with casting temperatures up to 1150 °C [1]. They showed that metal flow rate increases with temperature. And no gas layer was detected at the metal front, up to about 525 °C. When metal temperature was 750 °C, gas layer thickness was 5 mm and at temperatures higher than 1150 °C it was over 2 cm. Yang et al. used thin membrane pressure sensor in aluminum lost foam casting process and reported gas gap length of 1-3 mm [2].

At temperatures higher than 400 °C EPS vaporization rate increases and gaseous degradation products are formed at temperatures up to 827 °C. These gases predominantly consist of styrene monomer. At higher temperatures the monomer molecules undergo additional fragmentation yielding hydrocarbons [3]. Degree of this fragmentation depends on amount of heat absorbed by EPS and its degraded products; for example, Yao and Shivkumar reported that the volume of produced gases increase 230% with temperature increase from 750 to 1300 °C [4].

During mold filling, the foam pattern decomposes and escapes from the mold. At higher temperatures, complete decomposition occurs. The yield of styrene monomer is reduced and acetylene, ethylene and benzene appear in increasing amounts. Madorsky has pyrolysed small samples of polystyrene in vacuum at temperatures of 400 °C to 1200 °C; also their analysis of gaseous products indicates that the yield of styrene clearly shows a maximum around 500 °C. As the temperature is increase further, the products of degradation undergo greater fragmentation [5].

Stepanov et al. reported a gas yield of 40 CC/g in aluminum lost foam casting [6]. Lee reported a gas yield of 300 CC/g in cast iron lost foam casting [7]. Shivkumar et al. reported a gas yield of 230 CC/g in aluminum lost foam casting and 760 CC/g in cast iron lost foam casting [1].

In the present research gas generation capacity for steel and aluminum lost foam casting are investigated and for measuring gas gap length in Al and steel, photography technique are used.

Mold filling has historically been studied using several techniques: 1) transparent mold or photography technique. 2) Using real-time X-rays. 3) Using water simulation. 4) Using computer modeling. 5) Embedding position probes. Although real-time X-rays is an exact method for examining metal behavior in mold in the case of lost foam casting, the use of photography technique show more details such as gas gap length and its related reactions. Real-time X-rays technique can not show foam pattern and gas gap. Butler and pope

perhaps were the first to use photography technique in lost foam casting [8].

## II. METHOD

In this research photography technique was used to investigate mold filling time, metal front geometry and gas

gap length in lost foam casting [9, 10]. Diagrammatic experimental set-up and pattern dimension are shown in Fig. 1.

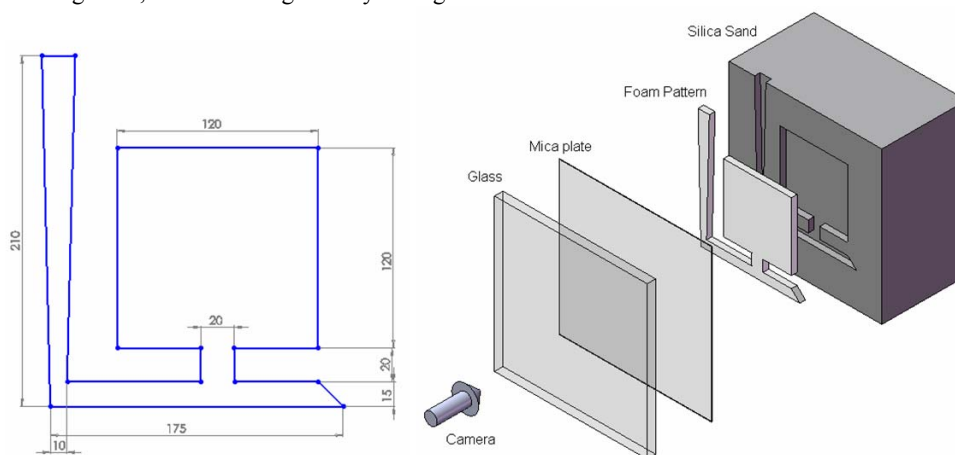


Fig. 1 Experimental set-up and pattern dimension in millimeter.

Patterns were prepared, using a hot-wire cutter, from solid EPS blocks with actual densities of 10, 20 kg/m<sup>3</sup>, a bead size of less than 2 mm. One side of pattern (side attached to the glass) was covered with paper tape and then dipped in high permeability alumina-base coating, adjusted to baume 50 (measured by hydrometer) to obtain a 0.2 or 0.35 mm coating layer thickness, when one or two layers were applied.

Then the tape was removed from the pattern and that face of pattern coated with florescent paint for increasing gas gap contrast in steel casting. The fluorescent paint is achieved by a highlighter pen on one face (front face) of the foam pattern. In this case we will have a fine contrast between the foam and background (i.e.: gap and liquid and sand) of the photographs, in which measuring of the Gap-gas will be easier and more accurate. Then, the fluorescent paint has not effect on the permeability of coating.

And then the prepared foam pattern was placed in an open top steel flask equipped with the security glass plate to record the event in the mold with a high speed camera. To increase glass durability, a transparent MICA plate in 0.5 mm thickness was placed between the foam pattern and glass. The flask was filled with unbonded silica sand AFS 50 and compacted (compact parameters had 50 Hz frequency and 2 mm amplitude). Castings were poured with steel and aluminum alloy. The steel was 1.7225 alloys and aluminum was A356 alloy. Table 1 shows the alloys composition. All steels were

melted in a 3 KHz induction furnace and steels were poured in the range of 1640-1660 °C. The aluminum was melted in a crucible furnace and pouring temperature was in the range of 700-720 °C. The effect of mold conditions, metal fill behavior and the foam-metal interface interactions were recorded during pouring.

1.7225 steel alloy (ST) and A356 aluminum alloy (Al) were poured in different conditions. Table 2 shows the different casting conditions.

1H means high density foam (nominal density 20 kg/m<sup>3</sup>) and one layer coating and 2L is low density foam (nominal density 10 kg/m<sup>3</sup>) and two layers coating.

A new method was used for measuring Gas Generation Capacity of Polystyrene in aluminum and steel lost foam casting which is shown in Fig. 2. Container made from steel and in side of it, two depressions were made with silica sand. In this method, melted aluminum or steel is poured on polystyrene foam in a closed container under pressure of neutral argon gas; volume of output gas from container is measured by gas flow meter. To perform this test, foam is settled in the left depression and melt is poured in the right depression, after closing the container, neutral gas is blow in it. After that flow meter is installed at the exit and container is become inclined to pour melt on the foam and decompose it. The volume of generated gas is measured by flow meter.

TABLE I  
ALLOYS COMPOSITION

A356	Al	Si %	Mg %	Cu %	Ti %	Fe %	Zn %	Mn %	Other , each%	Other , total%
	As remainder	6.50 - 7.50	0.25 - 0.45	<= 0.20	<= 0.20	<= 0.20	<= 0.10	<= 0.10	<= 0.050	<= 0.15
1.7225	Fe	C	Cr	Mo	Mn	Si	P	S	--	--
	As remainder	0.38- 0.45	0.9- 1.2	0.15- 0.3	0.2- 0.6	<0.4	<0.035	<0.035	--	--

TABLE II  
DIFFERENT CASTING CONDITION

Title	Molten metal	Coating layers	Foam density (kg/m <sup>3</sup> )
AL 1H	aluminum A356	1	20
ST 1L	Steel 1.7225	1	10
ST 2L	Steel 1.7225	2	10
ST 1H	Steel 1.7225	1	20
ST 2H	Steel 1.7225	2	20

Inclining of container is done one time without foam to measure the volume of generated gas from warming of cast; in measuring gas volume foam is deducted.

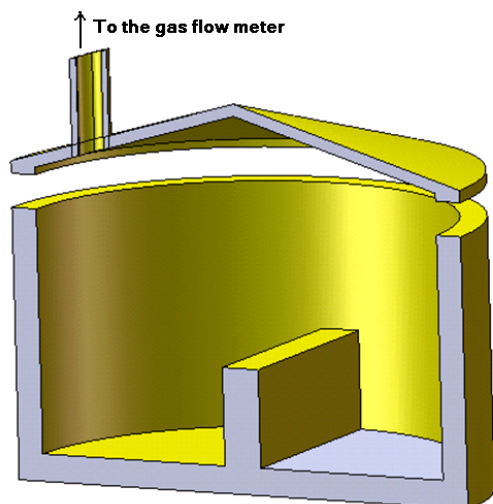


Fig. 2 Schematic of container

### III. RESULTS AND DISCUSSION

Although the glass window technique for metal fill behavior differ from real conditions of lost foam casting, by using this technique more details can be observed compared with other techniques such as real time X-ray.

Results of photography indicated that Gas gap length increases with increasing rise of metal front temperature and foam density, and decreased coating permeability. In steel lost foam casting, the volume of gaseous degradation products was significantly greater than aluminum lost foam casting [12]. According to Fig. 3 gas gap length in steel casting is larger

than aluminum casting. The gas gap lengths are shown in Fig. 4. In the case of aluminum lost foam casting no gas gap is detected and Liquid Expanded Polystyrene (LEPS) layer is smaller than 5 millimeter and Solid Expanded Polystyrene (SEPS) is mainly decomposed to LEPS. A little white gas escaped from the flask and it didn't combust when went out from flask. These gases mainly consist of styrene monomers. During mold filling of aluminum lost foam casting, LEPS were trapped between molten metal and the glass plate. In photography result, it was observed that LEPS boiled between molten metal and glass. LEPS didn't accumulate in metal front during mold filling, and LEPS were trapped between the metal and the coating or glass plate.

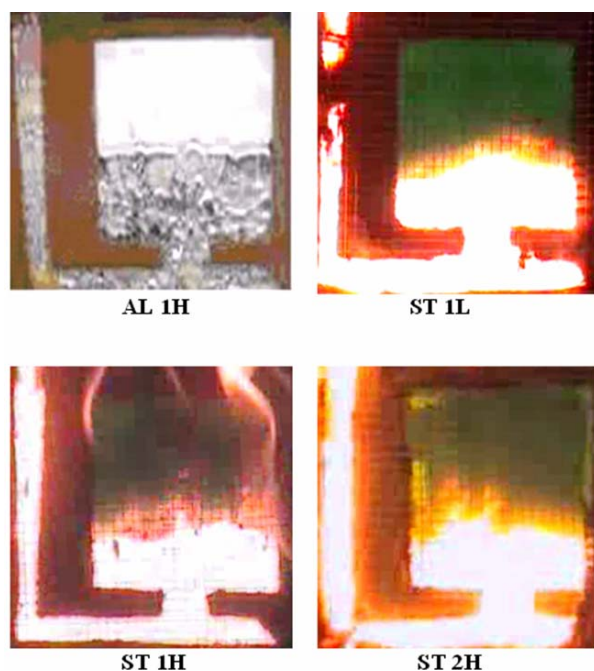


Fig. 3 Metal front and gas gap length in different casting conditions.

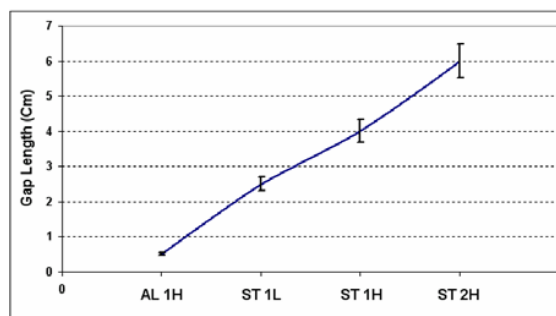


Fig. 4 gas gap length in different casting conditions.

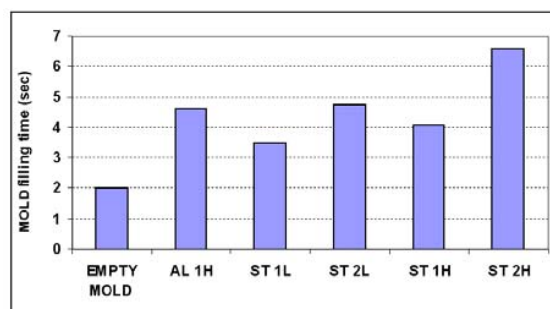


Fig. 5 Mold filling time vs. casting conditions.

In aluminum lost foam casting, several video frames at different times during filling illustrated that LEPS don't accumulate in the metal front and there is only a narrow band of LEPS between SEPS and the metal front. This narrow band of LEPS decreased heat flux from metal front to foam pattern. In aluminum lost foam casting the heat flux rate in the metal-foam interface (on the other hand kinetic of foam decomposition) control mold filling rate.

According to measurements in slides of photography technique, gas gap length in ST 2H was 6 cm and in ST 1H was 4 cm and in ST 1L was 2.5 cm; therefore coating thickness and foam density have a significant effect on the gas gap length in the lost foam casting process.

The results show that metal front temperature, foam density and coating permeability have significant effects on the volume of gaseous degradation products in ferrous alloys lost foam casting. By increasing casting section thickness or decreasing coating permeability, exposure time of degradation products to heat increases and then more atomic bonds break and the volume of gaseous products increases.

Mold filling time vs. different casting conditions are shown in Fig. 5. Two factors caused the increase of mold filling time when coating layer thickness is increased. The first is decreasing coating permeability and the latter is the increasing gas generation capacity.

The results of measuring the releasing capacity of gas foam indicate that the volume of generated gas due to foam decomposition in aluminum and steel casting are 50 CC/g and 3200 CC/g respectively.

This difference is indicative of more decomposition of polystyrene and breaking more numbers of carbon compound bonds in steel casting in relation to aluminum casting. The role of sand in the container of gas generation capacity measurement of aluminum and steel lost foam casting is to LEPS diffuse to it [11]. In the event that LEPS exposed to heat of molten aluminum more than that of real conditions, it undergoes more fragmentation and leads to additional generation gases.

Results of container test indicate that by increasing temperature, gas generation capacity increases.

If polystyrene completely decomposes to its monomers, 216 CC/g gas will be generated. The results of plunger test show that in aluminum lost foam casting only 20-25 % of the foam decomposes to the gaseous products and the remainder stays in the liquid state.

Results of photography indicate that with increasing foam density or coating layer thickness, the volume of the flame upon the flask (during pouring) is increased And, in steel lost foam casting, coating layer thickness has a significant effect on the volume of the gaseous degradation products.

If we assume that gaseous degradation products in steel lost foam casting mainly consist of hydrogen, gas generation capacity will be about 3200 CC/g in real casting conditions.

Base on ideal gas equation, (1) and the following assumptions, we have:

$$PV = nRT \quad (1)$$

$n = 4 \text{ mol hydrogen (H}_2\text{)} = 104 \text{ gr polystyrene}$

$P = 110000 \text{ Pa}$

$V = ?$

$R = 8.314 \text{ J/mol K}$

$T = ((T_f + T_d)/2) + 273$

That  $T_f$  denotes to the metal front temperature ( $\sim 1773^\circ\text{K}$ ) and  $T_d$  denotes to the foam decomposition temperature ( $\sim 433^\circ\text{K}$ ). The “T” temperature denotes to the average temperature of the gases in the gas gap in steel casting and it equals to  $1100^\circ\text{K}$ .

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#### REFERENCES

- [1] S. Shivkumar, X. Yao, M. Makhlof, “Polymer Melt Interactions during Casting Formation in the lost foam process”, Vol. 33, Scripta Metallurgica et Materialia, 1995, PP. 39-46.
- [2] J. Yang, T. Huang, J. Fu, “Study of gas pressure in EPC molds”, Vol. 128, AFS Transactions, 1998, PP.21-26.
- [3] S. Shivkumar, “Modeling of temperature losses in liquid metal during casting formation in expendable pattern casting process”, Vol. 10, Materials Science and Technology, 1994, PP. 986-992.
- [4] X. Yao, S. Shivkumar, “Molding filling characteristics in lost foam casting process”, Vol. 31, Materials science and Technology, 1997, PP. 841-846.
- [5] S. L. Madorsky, S. Straus, “Thermal Degradation of Polymers”, Society of Chemical Industry (London), monograph, 1961, PP. 13-60.
- [6] Y. U. Stepanov, V. G. Anuchina, V. P. Kirpichnikov, Russian Castings production, 1967, PP. 431-435.
- [7] H. S. Lee, “Forming Conditions of gray iron casting in full mold process with unbonded sand molds”, Vol. 10, AFS Transactions, 1976, PP. 559-570.
- [8] R. D. Butler, R. J. Pope, “Some factors involved in full mold casting with unbonded sand moulds”, The British foundryman, 1964, PP. 178-190.
- [9] S. H. M. Mirbagheri, P. Davami, N. Varahram, “3D computer simulation of melt flow in LFC process”, Int J Numer Meth Eng, 2003, PP. 58: 723.
- [10] P. Davami, S. H. M. Mirbagheri, “Simulation of mould filling in Lost Foam casting”, Vol. 16, Journal of Cast Metals Research, 2003, PP. 1-12.
- [11] L. Wang, S. Shivkumar, D. Apelian, “Effect of polymer degradation on the quality of lost foam casting”, Vol. 181, AFS Transactions, 1995, PP. 923-933.
- [12] M. Khodai, N. Parvin, “Pressure measurement and some observation in lost foam casting”, Vol. 206, Journal of Materials Processing Technology, 2008, PP. 1-6.