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EXPERIMENTAL STUDY CONCERNING ENERGETIC INTERACTION OF GAS BUBBLE WITH LIQUID METAL SOLIDIFYING IN SAND MOULD

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This paper summarizes experimental methods and results of the casting experiments conducted in foundry shop of N.C.E.T., Karachi to observe certain phenomenas about gas formation in SiO_2 based sand mould. The apparatus essentially consists of a mould in which alloys, e.g., Brass, Cast Iron and. Steel, were cast, connected with a manometer for measuring gas pressure, which was replaced by a baloon for collecting gas when analysis was required. The experimental datas collected have shown that gas pressure developed in the mould cavity varies in four ways: firstly it increases abruptly immediately after pouring, then it decreases slowly, followed by slight increase and then permanent decrease. The analysis of mould gas was carried out with gas chromatograph and was found to be essentially consisting of CO_2, CO, N_2 and H_2, O_2 and hydrocarbons. As a conclusion, the energetic interaction, giving behaviour of gas bubble at different stages of pressure versus the alloys with different rates of solidification and physical morphology of some of the gas defects, have been elaborated.

INTRODUCTION

When liquid metal comes in contact with mould surface, immediately large volume of gas is evolved from the mould. The sources of generation of gases may be divided in three categories:

(1) Substances present in the moulding sand e.g., water, volatile matters and other materials which decompose on heating at high, temperature. (2) liquid metal being cast in which gas has dissolved during melting, tapping and casting and (3) metal-mould reactions – the gas reactions taking place at metal mould interface.

The gas pressure in the mould cavity results due to the non-concordance between vel. of formation and evacuation of gas from the mould cavity and acts on the surface of contact between the mould and metal thus influencing directly on the blowholes and other casting defects. Value of gas pressure generated in core during casting of steel is greater than 0.3 Kgf/Cm^2 [1].

EXPERIMENTAL

In order to assure, authentic results, which may be generalised to both ferrous and nonferrous foundries, the phenomena of generation and pressure of gas was studied practically with three alloys, brass (60/40), cast iron and carbon steel cast in SiO_2 mould containing 1 % molasses, SiO_2 mould with 10 – 12 % molasses and green sand mould containing 2 % dextrin. In this way the analysis and pressure of gas formed in the mould are recorded at different time periods with all the three alloys and the results obtained can thus be applied to both ferrous and non-ferrous foundries.

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GENERAL PROCEDURE

In order to conduct casting experiment many test bars were considered and it was decided to use a rectangular test bar with an adequate height forming a cavity which can collect sufficient gas for experimentation (see Fig. 1). The dimensions of test bar were 6" x 2" x 2".

Moulding. The moulding was carried out in laboratory sized flasks of dimensions: 15"x 9"x 4" and three different types of moulding sands were used for casting brass cast iron and carbon steel. The composition and physical characteristics of these sands are given in Table 1. The facing sand was covered with backing sand and ramming was carried out mutually and also with pneumatic rammer. The facing sands were prepared in muller M/c of 50 lb capacity, fitted with two rollers of 10" dia, and 2" width, operating at R.P.M. 44. The mould cavity was provided with parting gate of 4" length and 3/8 inch dia, at the edge cavity and 2 at the sprue base. The down sprue was of 4" height, and 1" dia while dia of sprue base and sprue-cup was 2" each.

Melting. The carbon steel of type AISI 1030 comp. C=0.28 – 0.34 %, Si=0.15 – 0.3 %, Mn=0.6 – 0. 9 %

Table 1. Composition and characteristics of moulding sands used for casting different alloys.

Ingredients	Brass %	Cast iron %	Steel %
Wind-blow sand,	98	88-90	–
Natural bonded sand, 10% clay mesh			
SiO_2 35	–	–	20
– 48			25
Sand 70			20
100			20
Fire clay	–	–	2
Bentonite	–	–	8
Water	–	–	3
Dextrin	–	–	2
Molasses	2	10-12	–
Characteristics:			
Moisture	2.6	2.4	2.9
Permeability	150	154	163
Green compressive strength	0.20 kg/cm^2	0.24 kg per cm^2	0.35 kg/cm^2
Grade of ramming, mould hardness	85	85	85

S=0.05 %, P=0.04 % was melted in electric arc furnace of 13 tons capacity, with silica roof and magnesite lining in the hearth. The molten steel was tapped in ladle of 40 kg. capacity, lined with fireclay and preheated with ordinary gas flame for 75 min. The tapping temperature was measured with immersion pyrometer of range 1200 – 1700^o

The cast iron was melted in coke fired furnace of 5 feet height and 2 feet inner diameter lined with silica sand mixed in clay, provided with an electric blower for supplying air. Before operation, the furnace was cleaned and ash was removed from the bottom of the furnace. The grating was fixed at suitable height above the bottom. It was then covered with kindling wood and some lumps of coke. The kindling wood was ignited and when coke had caught fire, small lumps of coke were added. Then the preheated crucible of 40 kg. capacity containing cast iron scrape was placed in the furnace and crucible was covered from all sides with coke. The blower was started and blowing continued till content of crucible melted away. The temperature of cast iron was measured with Cr-CrNi hand thermocouple (200 – 1400^o). Melting completed in three hours.

40 kg of brass (60/40) scrape was melted in a gas fired furnace supplied with natural gas. The temperature of molten brass was measured with Cr-CrNi hand thermocouple (200 – 1400^o). Melting completed in two hours and "Lahori" salt (common salt) was used during melting for cleaning the metal.

Casting. Each of the mould used for experiments was provided with a hole of 3/4" diameter starting from upper surface of cavity upto outer surface of cope. In this hole a fireclay tube of 6" length and 1/2" inner dia., and 3/4" outer dia. was fixed. In this tube, another glass tube, as shown in the Fig. 1, was fixed. The leakage of gas from tubes was prevented by patching plaster of Paris, at the adjoining of tubes. The glass tube is then attached with required apparatus for necessary experimentation. Finally metal is poured in sprue cup and different phemomena are studied.

PHENOMENA STUDIED

Gas pressure. In order to study the variation in gas pressure developed in mould cavity, the part of tube . . T. . in Fig. . . 1 . . is attached with coloured water manometer (0 – 1000 mm), with a rubber tube and molten metal is poured in the sprue cup.

Gas Analysis. The gas evolved from mould cavity was collected in empty baloon by replacing manometer. No special gas was used as purger gas. The analysis was carried out in Bechman GCM gas liquid chromatograph provided with thermal conductivity cell. Hydrogen was used as a carrier gas in the apparatus. The absorbants were chromosorb 102 and 104. 0.5 ml volume. of gas was analysed in the reference column of same material on a flow rate of 40 ml/min at a temperature programmed and isothermal.

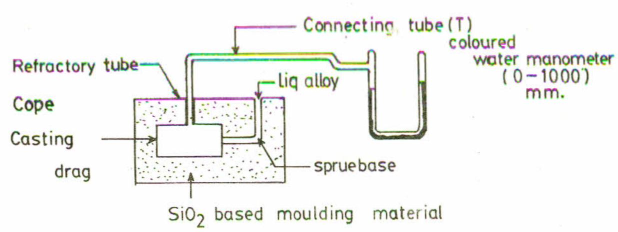

Fig. 1. Setting of apparatus for experiment.

EXPERIMENTAL RESULTS

Measurement of Gas Pressure. The gas pressure in mm, on water manometer was measured after each 15 sec. until it became zero. The time was measured with chronometer. The results obtained for each alloy are given in Table 2.

Gas Analysis. In order to judge the real nature of gaseous atmosphere from the mould cavity (as it was), the gas was taken from the mould cavity immediately 5 sec. after casting, in a baloon from which the air was sucked out. The analysis of gas is given in Table 3.

DISCUSSION

The careful observation of the gas pressure developed in the moulds of different materials, during casting both ferrous and nonferrous metals, has led to conclude that gas pressure, with passage of time after casting, fluctuates in four steps:-

Abrupt Increase in Pressure. When the metal is cast, just after pouring, approximately after 5 to 15 sec., the manometer records highest gas pressure. This is due to the rapid evolution of gas from the mould, when hot liquid metal flows on mould walls. Fig. 2 (a, b, c, stage I).

Table 2. The gas pressure, in mm of H_2O, in mould cavity during casting brass, cast iron and steel

Time after casting sec.	Brass	Cast Iron	Steel
0	0	0	0
5	112.5	123.5	173
10	120	125	125
15	123	112.5	112
30	87.5	95.5	50
45	75	75	52
60	17	62	65
75	15	50	63
90	17	51	62
105	24	52	57
120	24	62	51
135	24.5	62	49
150	25	64	45
165	24	65	37
180	23	63	35
195	23	57.5	28
210	15	52	25
225	12.5	51	23
240	10	50	15
255	7	48	12
270	–	25	7.5
285	–	10	–

Table 3. The chemical analysis of mould gas evolved during casting brass cast iron and steel.

Constituent	Brass %	Cast iron %	Steel %
O_2	21.40	20.37	0.4–1
N_2	78.13	76.33	3.96–8.66
CO_2	00.25	1.13	–
CO	00.22	2.17	–
H_2	–	–	53.41–60.06
H_2O	–	–	18
(H_2S+CO_2)	–	–	0.2–1
C_2H_{2n}	–	–	upto 0.2–1
C_nH_{2n+2}	–	–	5.34–6.83
–	Water free base	Water free base	–

Observation: The gas was taken from the mould cavity few second after pouring.

Slow Decrease. After reaching the maximum value, the gas pressure fluctuates rapidly for a very short period, and the gas collected in the mould cavity starts filtering through mould walls, because the mould is permeable. The gas pressure is thus decreased slowly. Fig. 2 (a, b, c stage II).

Slight Increase. The decreasing column of water manometer stops at one place for short period and then rises at relatively higher speed, up to the lower height thus indicating that decrease in gas pressure first becomes constant and then gas pressure slightly increases. This happens 60 – 165 sec. after pouring, due to rapid decrease in permeability of mould, as the particles of SiO_2 expand by intense heat of liquid metal. Fig. 2 (a, b, c stage III).

Permanent Decrease. After attaining the second maximum value the pressure starts decreasing and ultimately it comes to zero. Fig. 2 (a, b, c stage IV).

Due to the non-concordance between velocity of formation and evacuation of gas from the mould walls, the mould cavity is filled with the gases. The mixture of

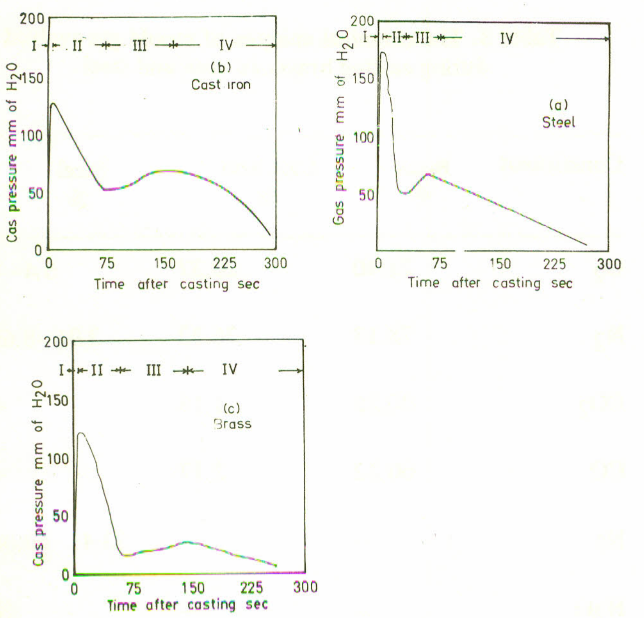

Fig. 2. Variati n in gas pressure developed in mound cavity during casting Steel (a) Cast iron (b) and Brass (c).

gases collected in the mould cavity create an oxidizing, reducing or neutral atmosphere, depending upon the percentage and nature of individual gas in the mixture. This is referred to as mould atmosphere. In $CO - CO_2$ atmosphere if $\frac{CO_2}{(CO+CO_2)}$ is greater than 10 %, the gaseous atmosphere is oxidizing, otherwise, it is reducing. At the lower temperature $27^o - 400^o$, in the presence of $H_2 - H_2O$ atmosphere, the medium is neutral and very weak oxidation of iron takes place [13].

CONCLUSION

The pressure of gas developed in mould cavity has close relation with the type of gas defects in castings. As a conclusion of series of experiments the author has suggested energetic interaction of gas bubble with liquid metal solidifying in SiO_2-base sand mould and on the basis of this interaction, the physical morphology of formation of different types of gas defects has been elaborated.

On the basis of rate of solidification, the alloys cast in SiO_2 based moulds can be divided in three general categories, i.e. alloys with high, medium and low rates of solidification and if all other conditions remain same, the alloy cast at high pouring temp. solidifies at high rate; thus steel will solidify at high rate while cast iron and brass will solidify at comparatively lower rates. During casting of metals or alloys which solidify at high rate, in the initial moments, when gas pressure reaches highest value (Stage I) the bubble appears in globular form and escapes from the liquid at high speed (Fig. a, 3) and afte- some moments when gas pressure reaches at Stage II, the "hard skin" forms on the casting, but this is broken by the gas bubble, thus forming "surface blowholes" (Fig. b, 3). When gas pressure slightly increases, the hard skin on the casting is also thickened and pressure of bubble is unable to tear it, thus settles under the "hard-layer" producing "sub-cutaneous blowholes" (Fig. c, 3). When the pressure reaches to Stage IV, the casting forms a thick hard layer on its all sides and bubble with the decreasing pressure, tries to press the surface of casting, creating gaseous macro-non-uniformity (Fig. d, 3) [14].

The alloys solidifying with medium rate e.g. rate of solidification is same as that of propagation of bubble, the bubble will precipitate from advancing solidifying front in Stage I and in Stage II when the pressure is decreasing, bubble will be proceeding at lower velocity than soldification front, but making a "way" through viscous solidifying mass (Fig. f, 3) which is further enlarged and broadened by slight increase in pressure (Fig. g, 3) in Stage III. This "way" after solification appears as "gas canal" (Fig. h, 3). The varying thinckness of gas canal shows variation in the pressure of gas bubble.

At low rate of solidification, the velocity of advancement of solidification front is less than speed of bubble and liquid mass is comparatively more viscous. The bubble which emerges from liquid viscous mass leaves a fine hole which acts as embroy for nucleation of other gas bubbles and progresses with the variable pressures (Fig. i, j, k) (3). The rate of solidification is little, therfore, alloy remains in liquid state and path of tiny bubbles coming from mould is blocked by the arms of dendrites. The bubbles setting in these dendrites appear as "pin holes" (Fig. 1,3).

When bubbles pass through the liquid metal the boiling of liquid metal in mould cavity is observed. According to

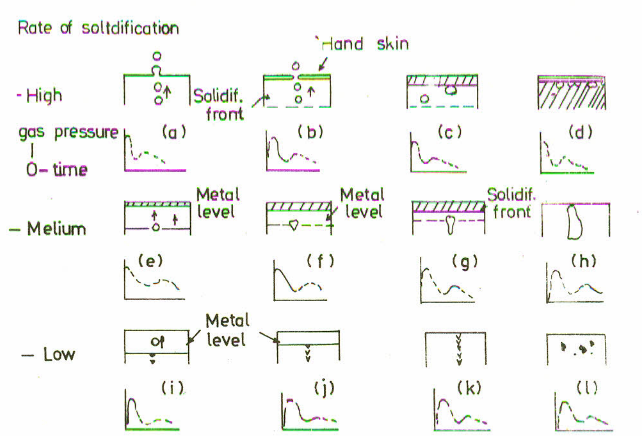

Fig. 3. Correlation between gas pressure developed in the mould cavity and physical morphology of gas defects in castings.

Medvedeev [6] "boiling" is of four types: (1) *Weak boiling:* It appears when difference (Ph-Pϕ) is little ((Pϕ is sum of atmospheric pressure, metallostatic pressure and surface tension of the liquid metal Phis gas pressure). This period of boiling lasts for short time and process of boiling is not observed. (2) *Strong boiling:* It is produced when difference (Ph-Pϕ) is greater. In this case relatively larger number of the bubbles penetrate in the liquid metal. (3) *Very strong boiling:* It is produced when (Ph-Pϕ) is greater. In this case the gas bubbles form packets of gas on the bar introduced. This type of boiling continues for larger period. (4) *Double boiling:* This occurs when process of boiling takes place in two stages, firstly immediately after casting and secondly when gas pressure once again develops due to decrease in the permeability of moulding material.

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