

## Effect of Different Cooling Conditions of Mold on Porosity for Pure Aluminum Castings

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**Abstract:** The results showed that liquid feeding is the dominant mechanism in pure aluminum castings. The porosity ratios and the coefficient of utilization of the length of the casting have varied. However, the best conditions that achieved a balance between the porosity and the coefficient of utilization of the length of the casting were the casting in a metal mold heated to a temperature of 400°C with the average porosity being 4.2%, while the coefficient of utilization of the cast is (98%). Gas porosity has also, been found to be dominant in pure aluminum castings, regularly distributed between the crystals and their boundaries and tend to be of a spherical shape.

**Key words:** Liquid feeding, pure aluminum castings, porosity distributio, metal mold, utilization, aluminum

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### INTRODUCTION

The use of aluminum and its alloys in various industrial fields is relatively recent in comparison to other metals and alloys. Aluminum has a high capacity to dissolve hydrogen in the smelting phase. It is the only gas soluble in the aluminum casting in large quantities. In general, solubility decreases with low temperature. This solubility reduces with the increase of silicon and copper in aluminum while manganese increases the hydrogen solubility (Han and Viswanathan, 2002; Guo and Mark, 2005). The cooling of metals is accompanied by the release of gases due to the large decrease in their ability with the freezing temperature. Thus, a quantity of gases will be formed when freezing. When the layers of the liquid are converted to solid state, gases are created at the line separating them. When there is no chance of their leakage, they will be confined forming gas (gaps).

It is commonly observed that gaseous gaps tend to be circular while the shape of deflation gaps is irregular (Anson and Gruzleski, 2001). It is worth mentioning that in case of metal oxidation, the inner walls of the gas gaps are covered with a layer of oxide and the small gas spaces are known as fine holes whereas the gas pores are defined as the gas gaps when they are large in size (Hand, 1989). When the hydrogen cannot be completely removed from the castings produced when freezing, it will cause a porous defect, be very smooth, highly dispersed or concentrated in a certain area of the cast. When the confined gas is in low concentration, it will lead to

formation of a fine porosity whose effect will be harmless. On the other hand, when some of the porosity defects are large and appear in the form of blow holes or cracks, they will lead to a decline in mechanical properties (Hand, 1989; Michael and Jones, 1990). The melting temperature and fluidity of molten metal are among the physical properties extensively affecting the ability of casting. The flowing property is the ability of the metal to flow freely inside the mold and fill its cavities well and completely. The fluidity of the metal depends on both the surface tension and the kinetic viscosity of the metal and the presence or absence of layers of oxides on the surface of the metal, as the surface tension of the metal varies according to the degree of its fusion, as it is of high values for the metal with high melting point and is low for metals with low melting point while the presence of oxides forms a cover around the molten metal and therefore it will be difficult or impossible for the metal to fill the narrow cavities of the mold. Therefore, the presence of oxides reduces the flow of the metal as it causes trouble when casting both aluminum or yellow copper (where a layer of zinc oxide forms) or bronze or some nonferrous alloys. As for viscosity, it is due to the variable effect of the specific gravity of metals as when comparing the viscosity of metals with the viscosity of water, we find it greater than viscosity of water by at least 2-4 times whereas when the viscosity is divided into the specific gravity (for the purpose of calculating the abstract viscosity) the metal's abstract viscosity in this case is less than the water viscosity and this would lead to a

**Table 1: Chemical analysis of pure aluminum 99.5%**

Element	Percentage
Al	99.500
Zn	0.090
Cu	0.014
Mn	0.090
Fe	0.130
Si	0.033

good flow. Therefore, proper pouring or casting temperatures should be used to keep the liquid metal's temperature above the freezing range for the purpose of filling the mold well. Studies indicate that what determines the metal's ability to produce defect-free castings is the surface tension rather than viscosity. It should also, be noted that deflation normally occurs as a result of the failure to compensate the liquid resulting from insufficient system of casting or feeders technology or from errors in the method of casting such as neglecting the feeder vehicle and the cut-off of casting before the feeder is replenished or the presence of sharp cavities in the design of models that freeze by the thin layer or as a result of depletion of the metal feeding, or failure to continue the direction of freezing during the process of freezing.

**Experimental procedure:** This study includes the fusion processes of the pure aluminum used in the research and the process of casting it in the sand or steel mold under the influence of different cooling rates and calculation of porosity ratio (whether gas porosity or shrinkage porosity), measuring the length of primary or secondary gaps and specifying the cast's coefficient of utilization in addition to the method of preparing the samples and imaging them with optical microscope and imaging the defects resulting during the casting process.

As for the alloys used in the research, they are of pure aluminum with commercial purity whose chemical analysis is indicated in Table 1.

The melting and pouring process has included turning the aluminum metal into castings ready to be cast with dimensions of (100×30×20) mm and melting these casts in a graphite crucible of capacity (5 kg) using the electric resistance furnace after heating it to the temperature of the pouring without treatment of gases dissolved in it. Then the slag from the fused metal surface is removed and then pouring the metal under one of the conditions described below:

- A cooled metal mold inside the oven
- A metal mold heated to 400°C and air cooled after the pouring
- A metal mold insulated from the top with silica sand and air cooled
- An uninsulated and air cooled metal mold

As for the calculation of the porosity values, the sample photos were taken to calculate the percentage of porosity using the method of intersection of lines where a mesh of horizontal and vertical lines was applied on transparent paper of fixed dimension 5 mm. This mesh was applied to the sample images to calculate the porosity intersection with horizontal and vertical lines by applying the following formula:

$$\text{Porosity percentage} = 100 \times \frac{B+A}{C}$$

Where:

A = The total lengths of porous intersection with horizontal lines

B = Vertical lines

C = The total lengths of horizontal and vertical lines

The results were then treated with the “surfer” software on computer, identifying the relationship (x-z) with contour lines to show the effect of different conditions on the amount of porosity and the nature of its distribution.

## RESULTS AND DISCUSSION

**Cooled metal mold inside the oven for pure aluminum alloy:** Figure 1a shows a very high rise in the average porosity ratio to 20.2% and a non-directional distribution. It is also, observed from the figure that it is highly concentrated at the upper surface of the cast.

This condition is attributable to the freezing behavior of the alloy of malleable freezing nature, done by the gradual freezing of the solid state in the form of interlocking dendritic arms which led to a decrease in the pressure of the liquid between the shrubs in the advanced stages of freezing causing a state of tension in these areas hindering the feeding process between the shrubs with no possibility to spread the shrinkage of the frozen metal in the isolated areas which led to the emergence of the contraction porosity and because of the very slow rate of cooling which led to the availability of sufficient time for it to cluster and become large in size and rough. As for the length of the tubular gap shown in Fig. 1b, it is small amounting to (14.5 mm) which led to a relative increase in the utilization coefficient which totaled (85.5%). It is unquestionable that the distribution of the total shrinkage in the cast in the shape of the porosity of shrinkage has helped to increase the coefficient utilization of the cast and led to a decrease in the length of the primary gap.

**Metal mold heated to 400°C for pure aluminum alloy:** Figure 2a shows the distribution of porosity in a study of pure aluminum cast which was poured into a heated metal mold to a temperature of 400°C before casting and

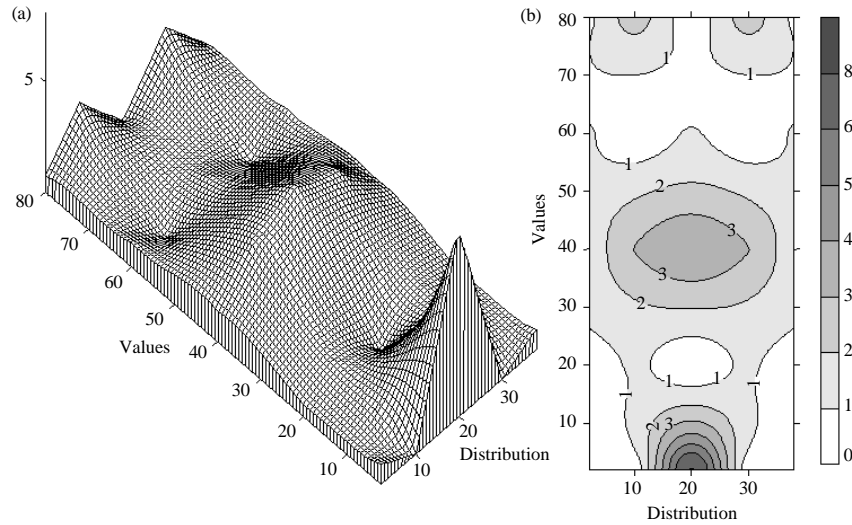


Fig. 1: a) Map of porosity distribution and b) 3-D diagram showing the porosity distribution of a pure aluminum casting poured into a cooled metal mold inside the furnace

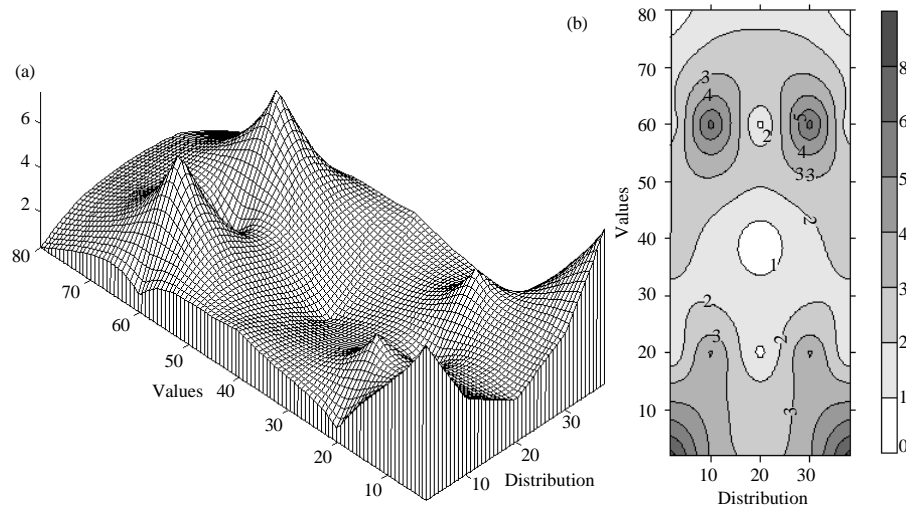


Fig. 2: a) Map of porosity distribution and b) 3-D diagram showing the porosity distribution of a pure aluminum casting poured into a metal mold pre-heated to 400°C

then cooled in the air where the average porosity ratio is (8.4%) with an incremental graduation from top to bottom to achieve its highest value in the middle of the bottom part of the cast, achieving a hot spot in this area.

The condition of the porosity in this casting is attributable to two things which are the slow cooling which resulted in a balanced freeze in expanded areas of the casting, i.e., total freezing and the second is the nature of the malleable casting freezing which led to the difficulty of feeding between the shrubs on the one hand and blocking the exit of hydrogen gas on the other. These conditions led to the high concentration of porosity ratio and the justification for this conclusion is the significant decrease in the length of the tubular gap shown in Fig. 2b

which reached 2 mm which led to a higher coefficient of utilization of the length of the cast reaching 98% and this implies existence of a mixture of deflation porous and gas porosity with a tendency for the porosity to cluster and concentrate along the crystalline limits.

**Metal mold isolated from the top with dry silica sand and air cooled for pure aluminum alloy:** Figure 3a shows the distribution of porosity in a cast section of aluminum alloy (4.6%) of copper poured into a metal mold insulated from the top with dry silica sand and air cooled after pouring with an average porosity ratio of 8.343% which is a high value with an irregular distribution, achieving its highest value is in the center of the cast.

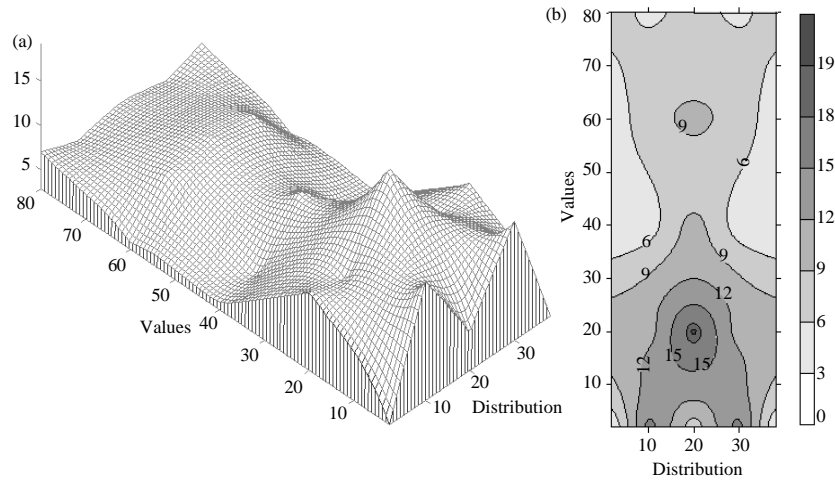


Fig. 3: a) Map of porosity distribution and b) 3-D diagram showing the porosity distribution of a pure aluminum casting poured into a metal mold insulated from top and air-cooled

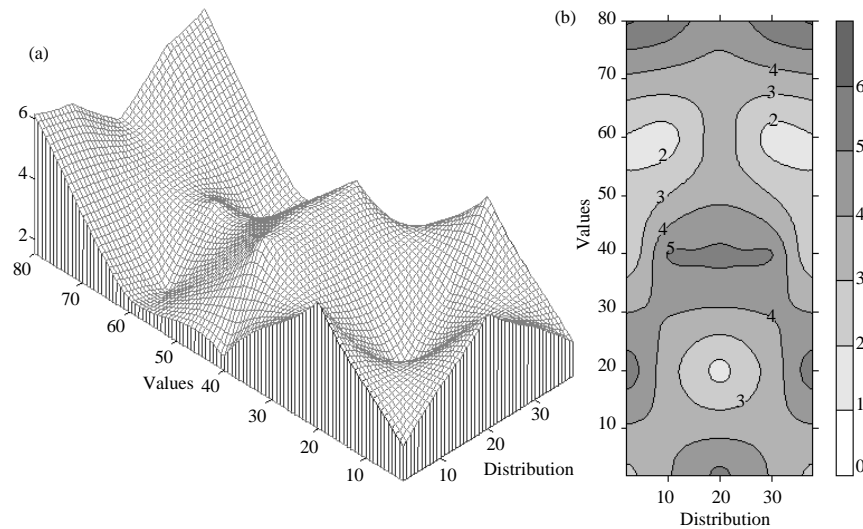


Fig. 4: a) Map of porosity distribution and b) Three-dimensional porosity distribution diagram for pure aluminum alloy poured into an air-cooled metal mold

The porosity in this cast is attributable to the effect of insulation from the top of the mold which led to a thermal gradient from the bottom to the top which in turn led to the of a state of total freezing in the lower part of the casting and retention of most of the hydrogen on the one hand and the difficulty of feeding between the shrubs which failed to compensate the deflation on the other hand, thus leading to a clear rise of porosity in this part of the casting and clear hot spots there with high porosity concentration. Figure 3b which illustrates the nature of the distribution of porosity at different areas of the cast, shows that the characteristic feature of the porosity is the clustering in interconnected groups and its presence

across the crystalline limits with a clear appearance of dendritic structure. These observations clearly indicate that feeding among the shrubs is the dominant mechanism here and that it failed to secure the liquid metal necessary to compensate for deflation, making the ratio in many areas appear varying. It was found that the length of the tubular gap was relatively large and the utilization coefficient was only 71%. For all of the above, this condition is one of the worst cases of castings.

**Non-insulated, air-cooled metal mold for pure aluminum alloy:** Figure 4a shows the porous condition in a cast section poured in a non-insulated, air-cooled metal

mold. The average porosity value in it totaled (3.8%) with a regular distribution across the molded body.

This is due to the achievement of a balance between the chances of the exit of gases and liquid feeding and feeding between shrubs. Also, the and solid feeding can contribute to one or more in achieving this regularity in the distribution and transfer of a large amount of deflation to the primary gap which gives a state of good balance between the proportion of porosity and its regular distribution as shown in Fig. 4b which led to a high coefficient of utilization of the cast which totaled (88%) where porosity is present and clustering along the crystalline limits and has a nature composed of both the gas porosity and shrinkage porosity.

### **CONCLUSION**

Gaseous porosity is predominant in pure aluminum castings. Liquid feeding is the dominant mechanism in pure aluminum castings. Porous distribution is concentrated regularly between crystals and their limits in

pure aluminum. Pouring in a heated metal mold is the best condition for the production of pure aluminum to obtain a balance between the porosity and the coefficient of utilization of the length of the cast.

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