Effect of ambient atmosphere on the foam expansion

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Abstract

The ambient atmosphere endorses or retreats surface oxidation of aluminium foam during foaming, thus affecting the maximal attainable porosity and pore size. These effects were investigated on foaming of four aluminium alloys using oxidising, protecting and as received atmosphere under various heating rates and pressures. It was found that aluminium alloys with higher affinity to oxygen (especially alloys containing magnesium) are very sensitive to the heating rate if they are not protected from oxidation. The surface oxidation significantly reduces the final porosity and is even able to inhibit the expansion of foamable precursor. Increasing of relative foaming pressure and/or foaming rate can diminish this effect.

1 Introduction

There is no doubt that the structural parameters such as pore size, pore shape and their distributions determine the resulting properties of aluminium foam. Since these parameters predominantly depend on chemical composition of foamed alloy, it is quite difficult to control them by changing of technological variables. The effects of foaming temperature, time, heating rate, and ambient pressure on the foam structure were already reported [1-5], however the foaming is very complex process and further explanations are still needed.

The essential expansion of foamable precursor starts above solidus temperature of the cell-wall alloy and continues until the precursor is completely melted. At each temperature the equilibrium is achieved between internal gas pressure in pores, resistance of the melt and external pressure on the foam. While the amount of gas evolved from foaming agent and external pressure unimportantly change with slightly increasing temperature, the essential driving force for expansion is the decrease of the resistance of melting alloy against stretching. This resistance depends on surface tension, viscosity and surface oxidation. Although surface tension and viscosity dramatically decrease on melting, the surface oxidation increases, especially in a case of aluminium alloys, when they are foamed in oxygen containing atmosphere. Therefore the expansion practically finishes, when the alloy is completely melted and further heating of foam above its melting point does not have a sense. It implies that the temperature range useful for foaming is predetermined by the composition of foamed alloy and thus the temperature cannot be taken as technological variable for the control of pore structure. The alloy composition influences also surface tension of liquid metal, its viscosity and affinity to oxygen. Thus, for given alloy composition, only the alteration of following parameters can affect the porosity:

- relative foaming pressure (difference between internal and external pressure)
- conditions promoting oxidation (time and atmosphere)
- conditions for drainage (gravity, time)

The main aim of this study is to describe the influence of ambient atmosphere on the oxidation of aluminium foams during foaming and its effect on the foaming kinetics and final porosity.

2 Experimental

The foaming trials with PM-foamable precursor (diameter of 20 mm, height of 5 mm) were performed in special laboratory equipment, which enables independent control of selected technological parameters. Four types of precursor based on Al-alloys (AlMg0.4, AlMg1Si0.6, AlSi10, AlSi12Mg1), with considerably different properties when melted (melting range, affinity to oxygen, viscosity and surface tension), were chosen for investigations. The foaming experiments were made in protective - (Ar), oxygen - (O_2) or “as received” atmosphere at variable external pressures (50-300 kPa) and different heating rates. Effect of internal pressure in the pores was examined using variable amount of TiH_2 (0.4-2 wt.%).

3 Results and discussion

The oxides arising on the foam surface during foaming increase the resistance of liquid alloy against stretching (foaming). As they are solid at foaming temperature, they have to be broken in a course of further expansion. The gas energy needed for rupturing of oxides cannot be efficiently used for expanding of pores. The rupture of thicker oxide may lead to a rupture of cell wall, which results in the loss of expanding gas. Both effects reduce the attainable porosity of the foam. After rupture of oxides, the melt surface oxidises immediately again. When the oxides are sufficiently thick, they stabilise the foam surface to such an extent that does not allow further expansion.

The brittle solid oxides on the foam surface may play some positive role on solidification and cooling; they stabilise the foam and prevent it from collapsing. However, if the volume of liquid foam is stabilised, the pressure inside the closed pores must decrease with decreasing temperature, according to the ideal gas equation of state $pV = nRT$. The arising pressure difference leads to corrugations of pore walls (for ductile alloys) or to their fracture (for brittle alloys). In the presence of brittle oxides at the foam surface the pore walls easily break thus producing defects in the structure. Moreover, surface oxides enhance the rupturing of pore walls also because they do not allow shrinking of solidifying cell wall metal.

The experiments confirmed the important role of oxidation. It decelerates the foam expansion significantly, especially for aluminium alloys with higher amount of magnesium, as they have higher affinity to oxygen (Fig. 1). The highest final porosity for all investigated alloys was achieved in protecting (argon) atmosphere. When the alloy with low tendency to oxidation is used (AlSi10), the final expansion depends only slightly on the type of ambient atmosphere.

Since the thickness (and also the strength) of the built-up oxide layer depends on time during which the melt is exposed to oxygen, the negative effect of the oxidation can be reduced with increasing foaming rate, e.g. by more intensive heating. As can be seen in Fig. 2 the foaming rate affects the final porosity only if good conditions for oxidation are provided. In protective atmosphere (Ar) no effect of foaming rate was observed for all investigated alloys. It is interesting for practice, that the alloys with low affinity to oxygen (e.g. AlSi10) are not sensitive to foaming rate also in as received environment.

Another way how to reduce the effect of oxidation is to increase the difference between pressures inside and outside pores. When the external pressure on the foam is reduced, the gas pressure in pores is able to break apart thick oxide layers and support the foam expansion (Fig. 3). However, if the pressure difference is too high, the pores can explode and foam collapses. The limit depends on physical properties of molten alloy, mainly on its viscosity and surface tension (external pressure of 30 kPa leads to collapse of AlSi10 foam, while in a case of AlMg1Si0.6 still enhances the foam expansion – Fig. 3).

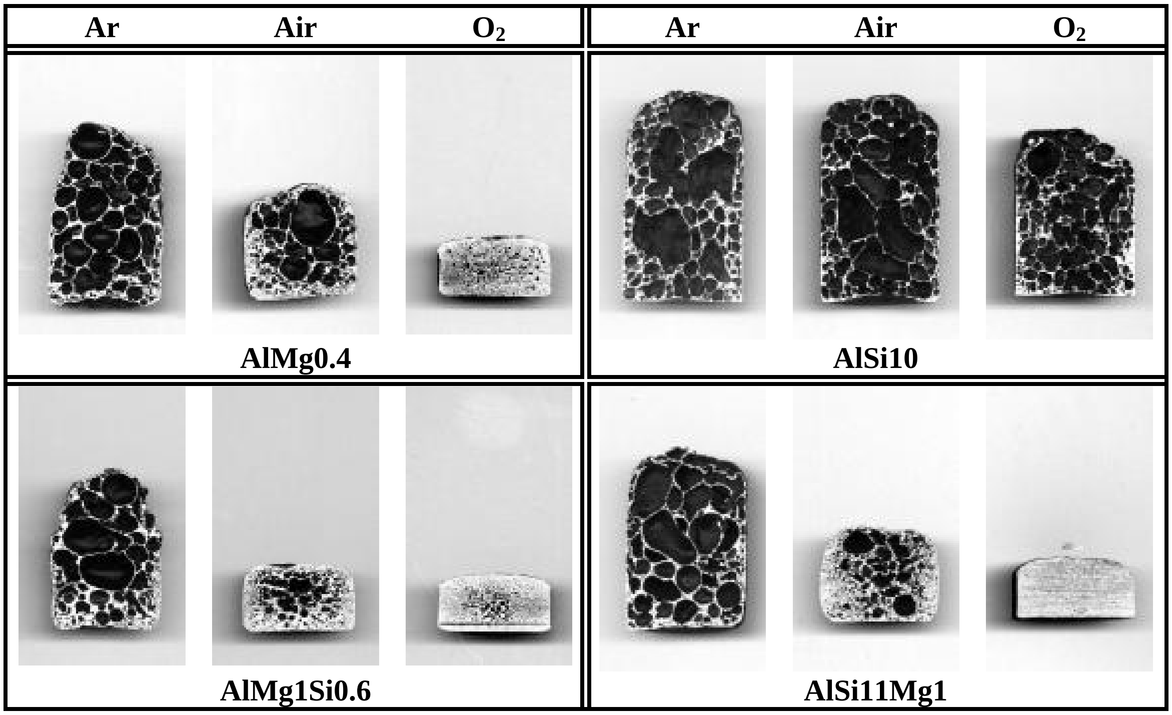

Fig. 1. Effect of the atmosphere on the foam expansion under constant heating conditions

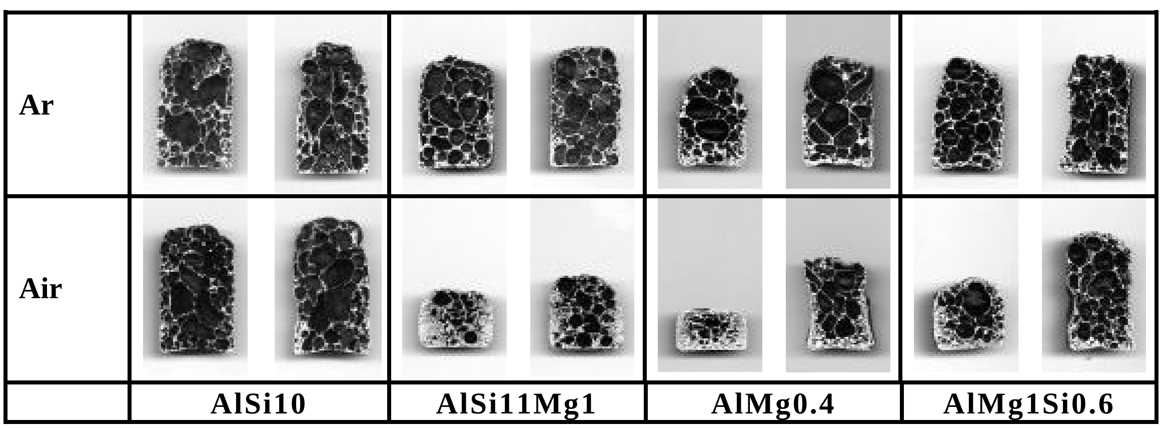

Fig. 2. Effect of heating rate on the foam expansion in protecting (Ar) and as received (Air) atmosphere (heating power: 2.6 kW - left, 3.6 kW – right)

Internal pressure in pores and thus foam expansion can be enhanced with increasing amount of foaming agent in the sample. Fig. 4 illustrates this effect at elevated external pressure (250 kPa). While 0.4 w.% of TiH_2 is not enough to fill the mould with AlSi11Mg1 foam, 2 w.% of TiH_2 leads to satisfactory results. The limits again strongly depend on alloy composition.

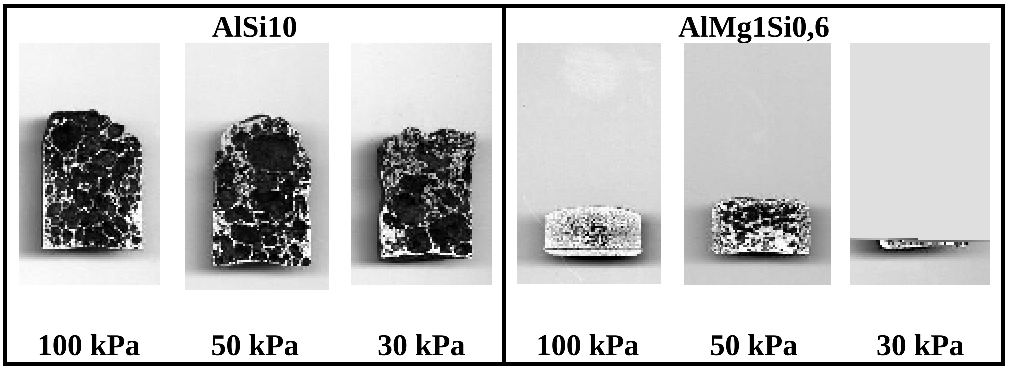

Fig. 3. Effect of external pressure on the foam expansion in oxidising atmosphere (O_2)

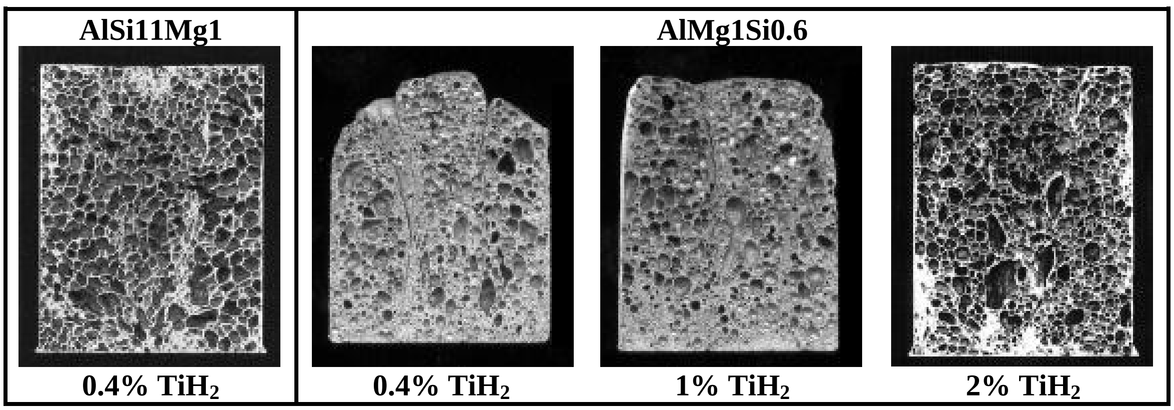

Fig. 4. Effect of internal pressure on the foam expansion under external pressure of 250 kPa.

4 Conclusions

It was shown, that the resulting porosity of foam is significantly reduced by surface oxidation during foaming, especially in a case of alloys with higher affinity to oxygen. These alloys are also very sensitive to foaming rate if they are not protected from oxidation. The foam expansion under oxidising conditions can be into some extent enhanced by increasing heating rate, use of protective atmosphere, reducing external pressure or by adding of higher amount of foaming agent.

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