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The Reason of Formation of Gas Porosity in Composite Castings with an Aluminum Alloy Matrix

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The paper presents the types of gaseous porosity occurring in composite castings in result of occlusion of atmospheric air during saturating of the composite reinforcement and liberation of gases while cooling and solidifying of matrix metal of the composite. A mechanism of gas occlusions formation is presented, as well as the factors causing the changes in their volume under the conditions of varying pressure in characteristic locations of the composite casting in the course of its production are discussed. The results of the analysis of gas liberation from the composite matrix, nucleation, and growth of the blowholes are provided. Conclusions resulting from the theoretical consideration are illustrated by the examples of porosity forms found by the authors in experimental composite castings.

Keywords: composites, porosity.

INTRODUCTION

Former studies on formation of the structure of metal matrix composite castings with saturated reinforcement have shown that their porosity may arise as a result of improper course of reinforcement filling, thus causing generation of gas occlusions, too low pressure of metal saturation, not guaranteeing appropriate filling of all reinforcement capillaries and improper course of the solidification process. This gives rise to shrinkage pores or even the pores formed in result of a gas released from metal [1, 2].

Porous reinforcement is saturated with a metal matrix under pressure [3 – 5]. In case of the course of the saturation process with the use of pressing method two stages shown in Fig. 1 may be distinguished.

In the saturation stage the metal in succession fills empty spaces of the reinforcement, as shown in Fig. 2, a. This is conducive to formation of gas occlusions of the volume exceeding the one of the reinforcement pores. In case of open pores the saturation pressure of temporary value *p* overcomes the capillary pressure and pressure losses related to metal flow through the capillaries [6].

Growing saturation pressure leads to compression of the gas occlusions closed in a reinforcement element subject to saturation. Maximal value of the imposed saturation pressure corresponds to minimal volume of trapped occlusions. A characteristic feature for this stage of composite structure formation allows to assume that the capillaries of the composite reinforcement profiles under saturation are filled with a two-phase, compressible mixture of liquid metal and gas occlusions. Maintenance of such a condition in which the whole volume of the manufactured composite casting is subject to the imposed pressure until full solidification of the metal matrix would, in consequence, lead to minimal porosity of the casting, that would be equal in its whole volume. Such a condition is reflected by a solid line in the third part of the plots of Fig. 1.

Under actual conditions of composite casting formation the casting may include (and usually does) some isolated areas [9]. There are such casting parts in which the matrix subject to cooling and solidifying is under the pressure of lower value as compared to its rated (imposed) level. This is due e.g. to partial or whole transmission of the punch or piston pressure to already solidified layer of

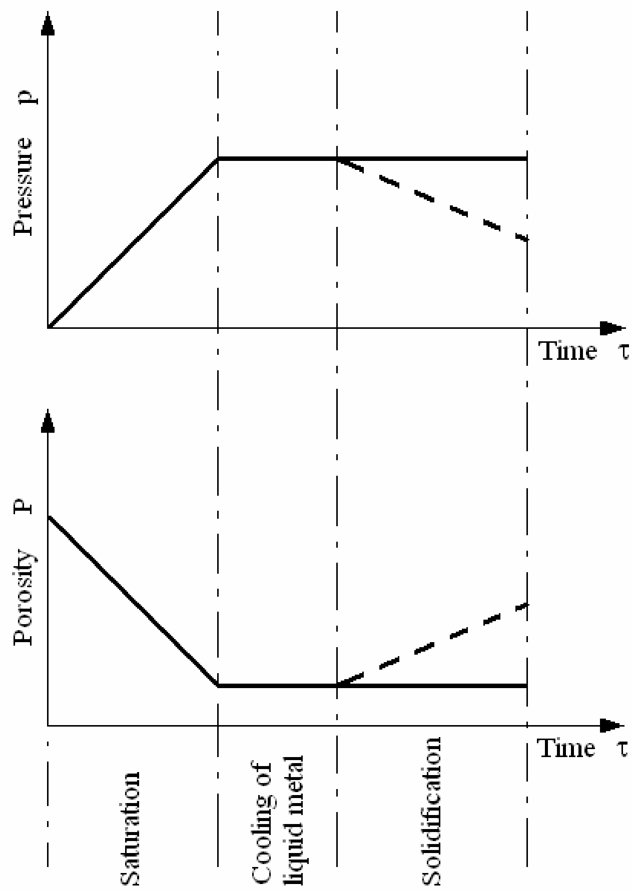

Fig. 1. Stages of composite formation

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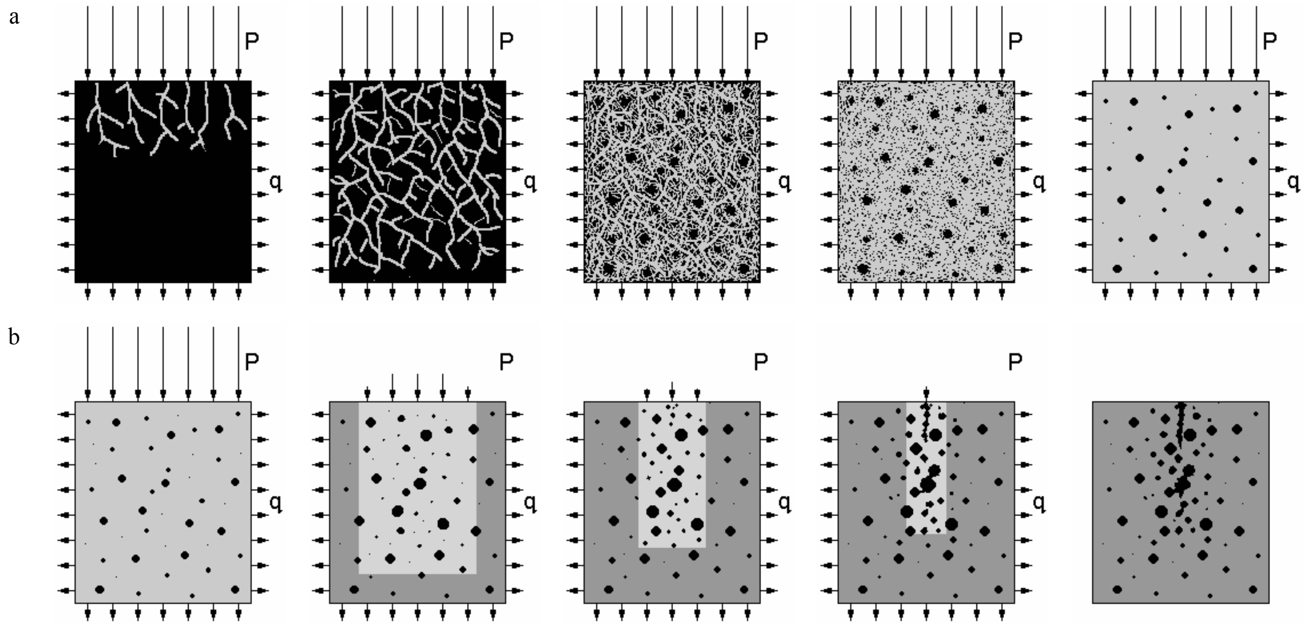


Fig. 2. A scheme of porosity formation in a composite casting with saturated reinforcement [7, 8]; a – the stage of reinforcement saturation; b – the stage of cooling and solidification of the composite matrix

the composite matrix. Stopping the piston (or punch) motion together with shrinkage of cooling and solidifying matrix leads to the situation in which the volume loss of liquid composite matrix metal is compensated with increased volume of trapped occlusions in the part of the casting with the matrix being still liquid. Porosity of the composite structure in the course of formation grows, but the volume of the pores under formation must not exceed the sum of volume loss of the cooling and solidifying matrix. Therefore, maximal porosity of the composite material occurs in the region of the composite matrix metal of the isolated area that solidified as the last. This condition corresponds to the broken lines in the third part of the plots in Fig. 1 and in the diagram of Fig. 2, b.

Apart from decompression of the gas occlusions during the process of matrix solidification of a composite casting some blisters may arise, including a gas, mainly hydrogen, released from the solution [10]. Conditions for formation of such blisters are as follows:

- supersaturation of the solution, determined by gas contents of the solid matrix metal in the solidus temperature, by the temperature, and the value of local pressure;
- possibility for nucleation and growth of the blisters of released hydrogen.

Objective of the present paper is to present the role of two above mentioned types of gas porosity for formation of the entire porosity of composite castings considered by the authors.

The gas-supersaturation is determined by the relationship:

$$\Delta S = S - S_r \quad [\mathrm{cm^3/100\ g}], \tag{1}$$

where S is the actual metal gas contents [cm^3/100 g], S_r is the gas solubility under local pressure and solidus temperature in solid state [cm^3/100 g], calculated from the expression

$$\log S_r = \frac{1}{2}\log p + \frac{A}{T} + B\,, \tag{2}$$

where p is the local pressure in the metal, MPa; T is solidus temperature, K; A,B are metal characterizing coefficients.

The relationship formulated for aluminum in solid state, the temperature approximating its melting point (660 °C), and various pressures, marked with a solid line, is shown in Fig. 3. The same figure presents hydrogen solubility in liquid aluminum (720 °C) under normal pressure (0.1 MPa) and the range of common hydrogen contents in aluminum and its alloys designed for casting [11].

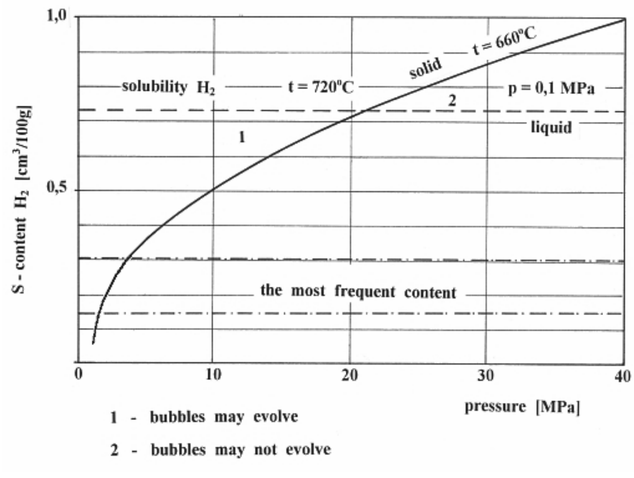


Fig. 3. Possibility of hydrogen desorption from liquid aluminum as a function of pressure: 1 – the desorption condition is met and the blisters may release; 2 – the desorption condition is not met and the blisters can not release

A blister may nucleate and grow provided that the balance pressure p calculated from the formula (2) exceeds the pressure within the blister p_p, defined as a sum:

$$p_p = p_k + p_z \ , \ \text{[MPa]} \qquad (3)$$

where p_z is the local metal pressure, MPa; p_k is the capillary pressure, MPa.

A diagram of nucleation and growth of a blister in the reinforcement element is shown in Fig. 4.

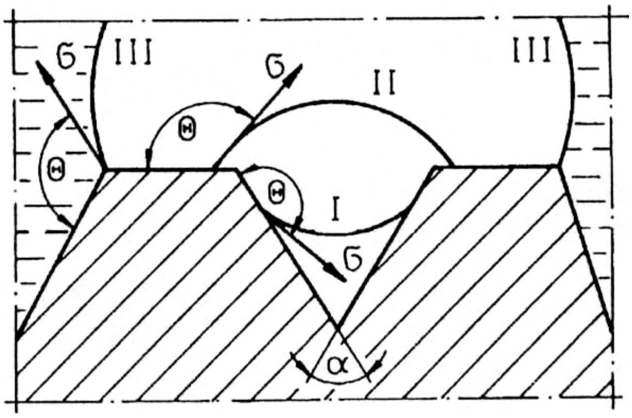


Fig. 4. Diagram of heterogeneous nucleation and growth of blisters

The ratios of capillary pressure p_k in the considered blister to the pressure p_{kk} inside a spherical blister for various wetting angles θ and the α angle characterizing geometry of the background, on which the blister grows, are shown in Fig. 5. It becomes clear that the capillary pressure may even have negative values.

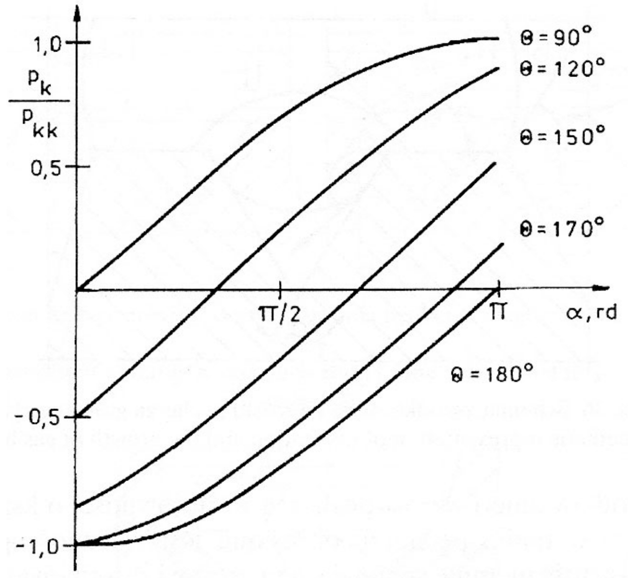


Fig. 5. The p_k/p_{kk} ratio for various θ and α values

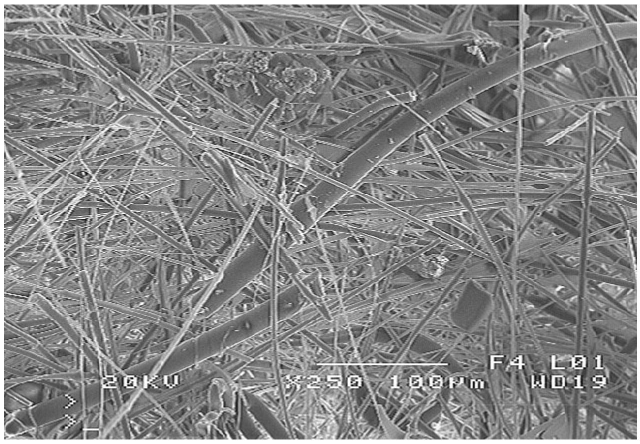
Taking into account the values of:

- a local pressure in the metal in isolated areas,
- capillary pressure in the blisters forming in the composite reinforcement elements,

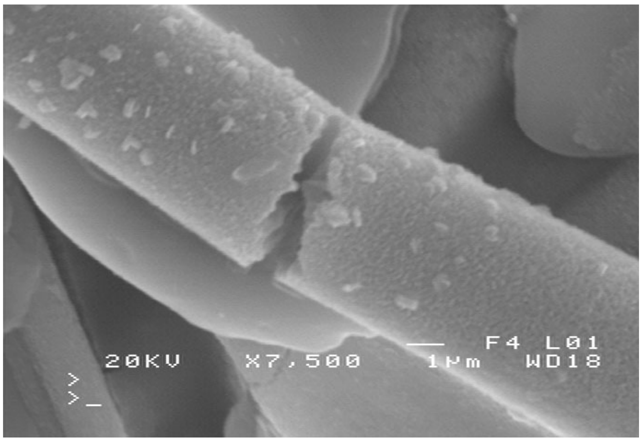
it should be found that, apart from occurrence of enlarged gas occlusions the hydrogen blisters may be released from the isolated area during solidification of a composite casting.

2. EXPERIMENTAL RESEARCH

Conclusions drawn from the above mentioned consideration were verified based on experimental composite castings obtained in pressurized saturation of a porous aluminosilicate reinforcement with an AlSi11 alloy. Reinforcement structure is shown in Fig. 6.



a



b

Fig. 6. Structure of the reinforcement made of pressurized aluminosilicate fibres

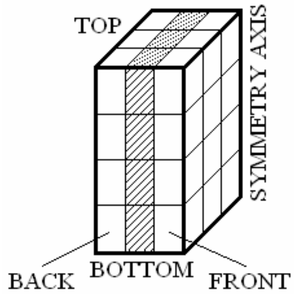
The structure shown in Figure 6, a, indicates that for purpose of filling with metal the space located between the fibres a considerable pressure is necessary. Figure 6, b, shows the cracks in the matrix fiber, that might be the location of gas blister nucleation.

The saturation process of composite reinforcement was effected in a pressure casting die mounted in a pressure machine IDRA OL320. The experiments were performed in a commercial aluminum alloys foundry.

The casting shape is shown in Fig. 7, a. Composite part of the sample (marked as "O") had the dimensions (70×60×20) mm. Every composite casting was cut in its symmetry plane and one of its halves was then cut according to the scheme of Fig. 7, b, into 36 samples. Each of them was then assessed with regard to its porosity (with gravimetric method). Example porosity distribution found in one among so examined castings is shown in Fig. 7, c.

a

b



c

Porosity distribution [%]								
front			middle			back		
0,81	0,68	0,78	0,69	0,78	0,97	1,08	0,94	1,04
1,26	1,04	1,14	0,81	1,73	4,07	1,46	1,33	1,21
1,29	1,03	1,36	1,02	2,32	5,01	1,53	1,47	1,42
1,36	1,60	1,76	1,15	2,49	3,79	1,92	2,08	2,11

Fig. 7. The shape of casted sample – a; its division – b; example of porosity distribution – c

A comprehensive gravimetric examination aimed at investigating distribution of pores in trial composite castings was complemented by assessment of polished metallographic specimens. The studies enabled identification of pore types and, in consequence, drawing conclusions regarding their formation.

The pictures in Fig. 8 show gas miniocclusions trapped between the composite reinforcement fibres. Clear spherical form of the occlusions confirms the fact that the processes of reinforcement saturation, cooling, and solidification occurred under low pressure (~5 MPa).

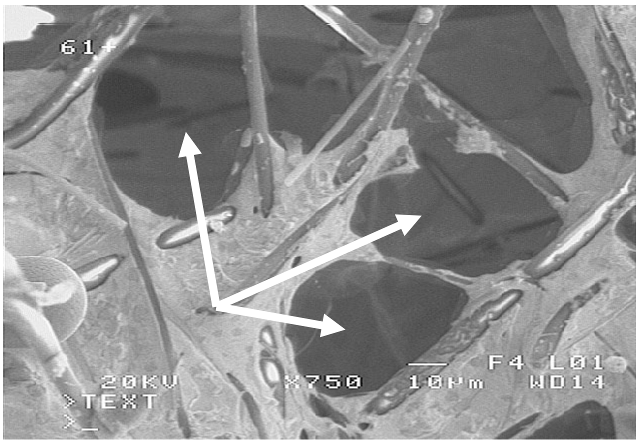
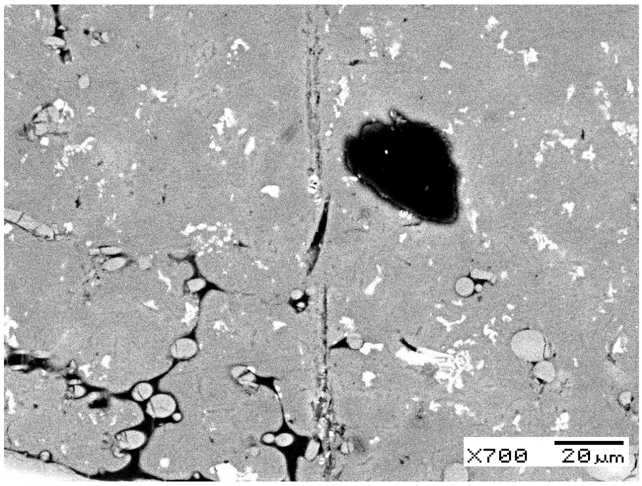
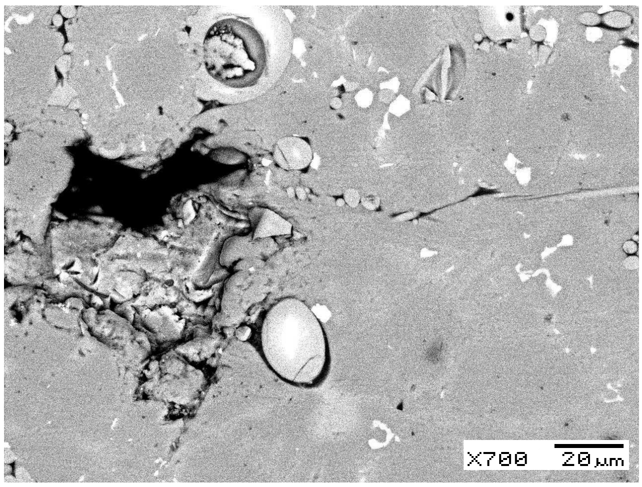


Fig. 8. Gas miniocclusions trapped between the composite reinforcement fibres

Fig. 9 presents two large gas pores being occlusions. The Fig. 9, a, shows the pores, one of them being spherical, while the other (in the left bottom corner) having a widely extended surface. The composite casting was saturated under the pressure of 100 MPa. The spherical occlusion is located in the area devoid of the reinforcement, the other "pressed" among the reinforcement fibres. Fig. 9, b, presents a large occlusion deformed on ceramic reinforcement material.



a – ak 47IV-27



b – ak47II-25

Fig. 9. Various shapes of gas occlusions (magnification 700×)

Fig. 10 shows a minor gas blister located at the reinforcement fibre. Dimension and location of the blister gives evidence that it has been formed in result of heterogeneous hydrogen nucleation at the reinforcement fibre.

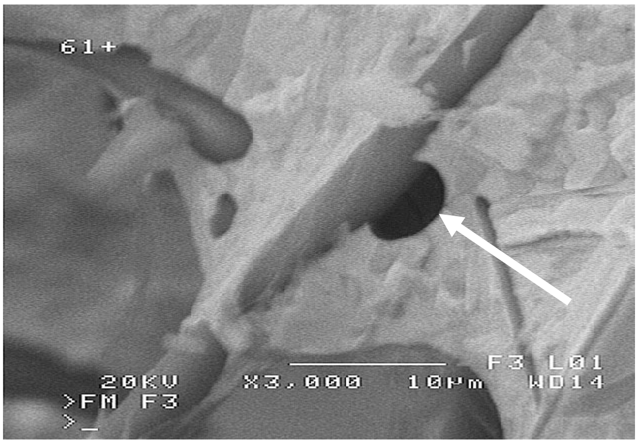


Fig. 10. Hydrogen blister formed at the composite reinforcement fibre

A large gas occlusion is shown in the picture of Fig. 11. It was found on the polished specimen taken from the isolated part of the casting. Initially it had a regular shape but reduction of local pressure in result of shrinkage of the cooling and solidifying matrix gave it clear decompression features. Occlusion contours marked with arrows clearly indicate the course of such a process. Mechanism of formation of the occlusion allows to call it a gas-shrinkage pore.

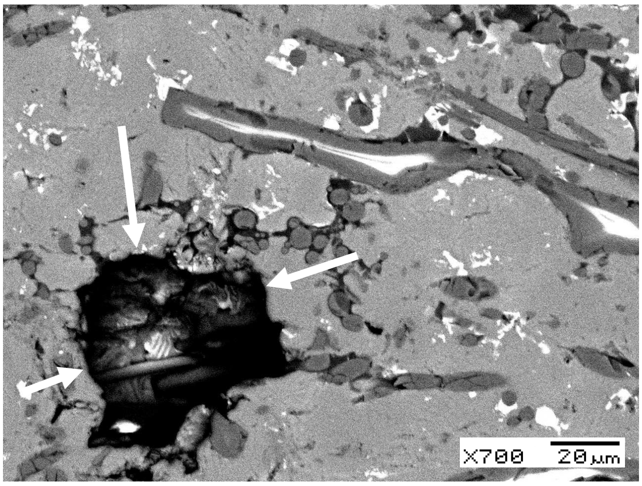


Fig. 11. Large gas occlusion with clear decompression features (magnification 700×)

CONCLUSIONS

1. Analysis of the course of formation of a composite casting with saturated reinforcement has shown that in some areas, considered as isolated regions, the pressure is lower than the one acting on the casting. In consequence, the blisters of occluded gas may grow in these regions and, moreover, the blisters of hydrogen solved in the metal may be released from there.
2. Studies on composite structures formed by saturation of a porous reinforcement made of short ceramic fibres with a liquid matrix metal give evidence to occurrence of both types of gas porosity in them.
3. Analysis of porosity and its distribution within the volume of examined samples, and observation of the shape and location of pores confirmed correctness of the Author's conclusions on formation of gas porosity in composite castings subject to the present study.
4. Knowledge of the mechanism and conditions of gas porosity formation in composite castings with saturated reinforcement enables forecasting this feature of the casting material and, in consequence, correct design of the castings and their manufacturing technology.

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