Study of the validity of the Niyama criteria function applied to the alloy AlSi7Mg

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The presence of porosity in metallic components produced in foundry, is one of the most undesired phenomena. It is now possible to predict the evolution and development of this event using modern software to simulate solidification. This give the foundry industry enormous assistance and is an useful tool for processes development.

Key words: aluminium and alloys, solidification, foundry

INTRODUCTION

Research on this topic started at the beginning of the last century and the literature contains numerous and wide-ranging articles. Since a precise description of these studies lies outside the scope of this paper, we focus our attention on the arguments most closely related to our work, and refer the reader to more specific references and to the literature we have reviewed [5-54].
The research of Niyama et al. [51-52] is significant throughout many of these studies, as shown by the frequent citations in a great number of works. Treating the phenomenon in a simplified manner, Niyama correlated porosity to thermal parameters and found that castings were sound only over a certain limit value of his function.
The function is:

$$N = G_s / \sqrt{\dot{T}}$$

where
N = value of Niyama function;
G_s = thermal gradient [°C/cm] ;
$\dot{T}$ = cooling rate [°C/s].
The function is very suitable for direct use with computers, thanks to its simplicity and the limited parameters needed. This is surely contributes to its wide utilization. The limit value of the function is dependent on the constants of the material and of the system.
Niyama conducted a great number of experiments on steel. It was demonstrated that the model works quite well on steel, but less well with different metals, in particular alloys with a wide interval of solidification. The limit values proposed in the literature for various metals are shown in table 1.

Material	Limit value
Steel	1
Cast Iron	0,75
Al alloys	0,25-0,30
Cu alloys	1,3

Table 1 – Limit value of the function of Niyama.

Tabella 1 – Valori limite della funzione di Niyama.

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Memoria vincitrice del premio Aldo Daccò 2004

The objective of our investigation was to estimate the reliability of the Niyama function in predicting the development of porosity in castings of the aluminium alloy AlSi7Mg.

EXPERIMENTAL METHODS

The alloy used was AlSi7Mg, widely used in the foundry industry and with well-known behaviour. Table 2 shows the nominal mechanical and thermal properties of this alloy, and table 3 shows its chemical composition.

Denomination	UNI 3599 ; A356 ; AlSi7Mg; G Al Si 7
Density (kg/m^3)	2670
Interval of solidification (°C)	620-559
Thermal Conductivity (W/m°K)	138,171
Specific heat (J/kg)	963
Latent heat (J/kg)	389391

Table 2 – Specifications of the alloy.

Tabella 2 – Dati della lega.

Element	Per cent value
Si	6,50% - 7,50%
Cu	0,05% - 0,10%
Mg	0,25% - 0,45%
Mn	0,40% - 0,60%
Fe	0,50% - 0,70%
Zn	0,05% - 0,10%
Ni	0,05% - 0,10%
Ti	0,10% - 0,20%

Table 3 – Nominal chemical composition of the AlSi7Mg (%wt.).

Tabella 3 – Composizione chimica della lega AlSi7Mg (%wt).

The efficacy of the model was evaluated comparing the real porosity level, obtained in castings produced in foundry, with that which would be predicted by calculations using the software programme.
We chose to study the behaviour of eight bars with cross sections of varying dimensions.
We considered two thicknesses, four lengths and two shapes of the section of the gating system.

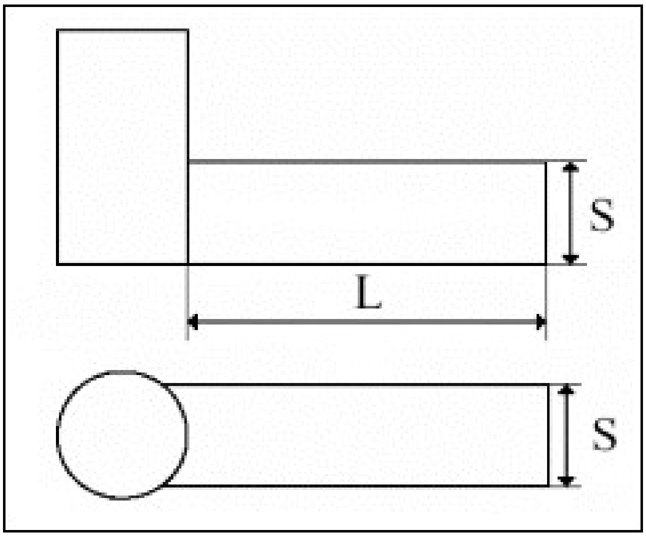

Fig. 1 – Specimen. *Fig. 1 – Provino.*

Name	Thickness S (cm)	Length L (cm)	Running system
10A-r	10	30,5	Rectangular
10A-c	10	30,5	Circular
10B-r	10	61	Rectangular
10B-c	10	61	Circular
15C-r	15	38	Rectangular
15C-c	15	38	Circular
15D-r	15	78	Rectangular
15D-c	15	78	Circular

Table 4 – Dimensions of the specimens.

Tabella 4 – Misure dei provini.

Figure 1 shows the samples; table 4 reports their characteristics.
The risers were put at one end of the bars and were designed using the Caine method [3].
The ingates were put at the side of the riser, as shown in figure 2.
We chose an unpressurized gating system with a gating ratio of S_{sprue}/S_{ingate}=1/2 [1], [3].

Simulation

The simulations were made with the commercial software SOLID CAST created by "Finite Solution". The programme, based on the finite difference method (FDM), calculates the equations of thermal transmission and shows outputs such as thermal variables (thermal gradient, solidification time) or functions (Niyama), through 2D and 3D images. We utilized the programme to calculate the Niyama function in the samples and thus to locate the zones where the limit values were not exceeded. In these zones the presence of porosity was predicted.
Figure 3 illustrates the results for the sample 15D-c through a cut-plane plot, that shows data inside the casting in a 2D image.
The data of the materials used were entered into the software programme to run the simulations.
Three castings, with thermocouples inserted in the centreline of the bars and in the sand, were made to obtain experimental data to verify and calibrate the software.
In the simulations it was not necessary to draw the entire pouring system; instead it was enough to insert the runner because the software does not have a fluid dynamics modeller. Solid Cast has only a simplified simulation of the mold filling, based on Bernoulli principle and conduction equation. Figure 4 shows a simulation in process during the mould filling.

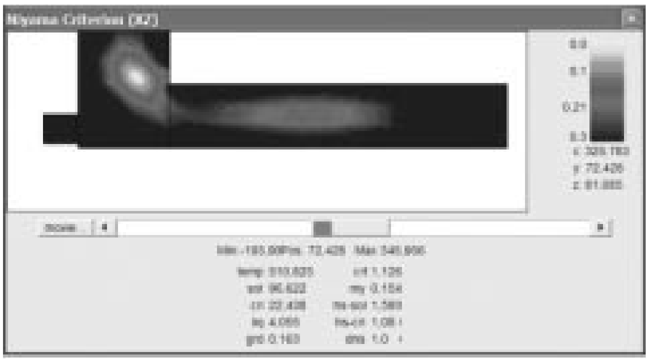

Fig. 3 – Visualization of the result through 2D image of the criterion of Niyama for the specimen 15D-c.

Fig. 3 – Visualizzazione dei risultati attraverso un'immagine 2D dei valori di Niyama per il provino 15D-c.

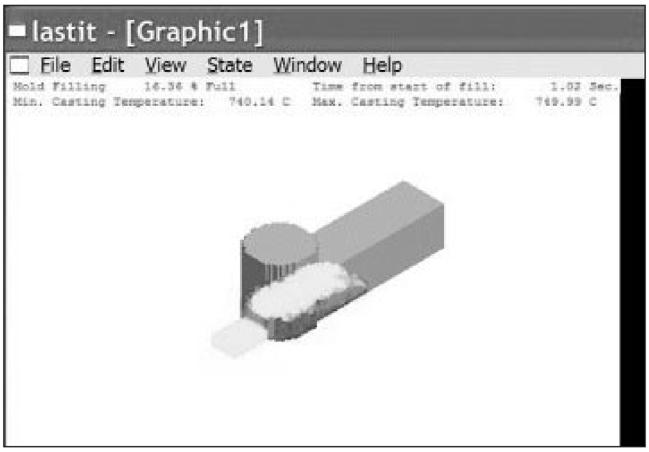

Fig. 4 – Simulation working, the entrance of the metal in the model.

Fig. 4 – Simulazione in corso, ingresso del metallo nel modello.

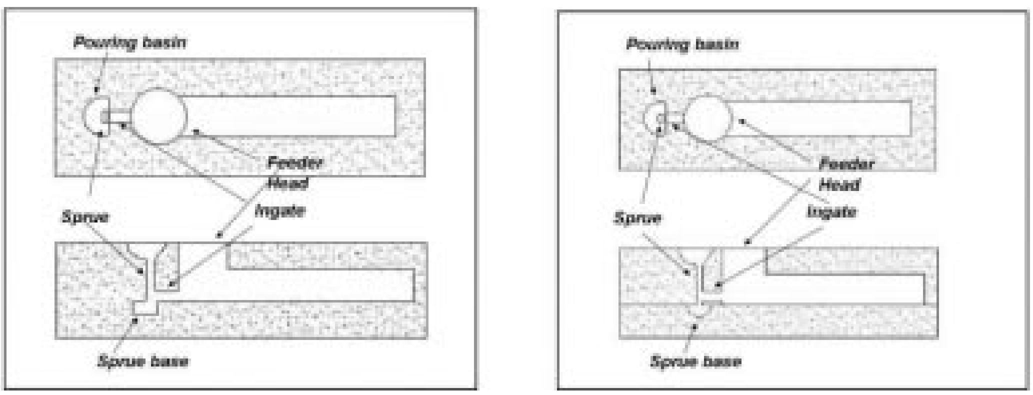

Fig. 2 – Rectangular (left) and circular (right) section of the running system.

Fig. 2 – Sistema di colata a sezione rettangolare (sinistra) e circolare (destra).

Experimental procedure

The castings were made using wood models, formed in silica sand and resin, and then poured in gravity.
We used silica sand with grain fineness AFS 55-60 and alkyd resin as binder. The parts in contact with the liquid metal were painted with a zircon water based varnish. We did not put any type of filter in the feeding canals and the liquid metal was not treated not outgas.
The metal was melted in a gas furnace, allowed to rest, and poured at a temperature of 750°C. All castings were poured from the same bath.

Fig. 5 – The moulds (upper), the eight specimens (lower).

Fig. 5 – Le motte (in alto), le otto fusioni (in basso).

Fig. 6 – The two types of gating system: rectangular (left) and circular (right).

Fig. 6 – Sistema di colata a sezione rettangolare(sinistra), circolare (destra).

Results and discussion

The castings were optically analyzed to evaluate the presence of porosity. We chose a rectangular area of 50 mm^2 in the centre of the bars as investigation zone. The micrographics were made at 25X. The samples were not chemically attacked. The porosity per cent level was estimated with an image analyser (Image ProPlus).
In this way we gained some comparative values from the simulations. The expected level of porosity was evaluated comparing the values of the Niyama function, calculated as the average of four points taken near the investigation zone, with the limit value. The presence of pores was expected in the zones where the limit value was not exceeded.
At the end, the values of simulated porosity were compared to real values.

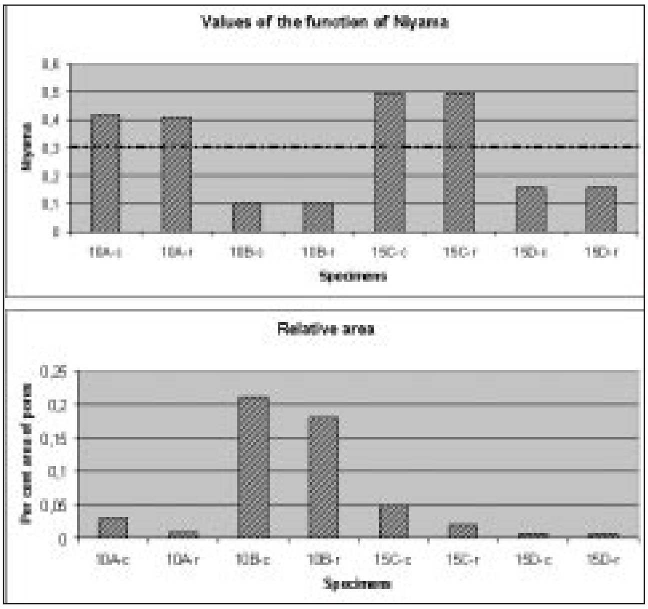

Fig. 7 – Value of the function of Niyama (upper); relative area of the pores in the specimens (lower).

Fig. 7 – Valori della funzione di Niyama (in alto); valori percentuali della porosità nei provini (in basso).

Figure 7 shows the results of the study: the upper diagram represents the calculated values of the Niyama function, while the lower diagram shows the porosity level in each sample.
Observing the simulations we can see that pores developed in the four longest castings: 10B-c, 10B-r, 15D-c, 15D-r. The worst situations are those predicted in 10B-c/r, followed by 15D-c/r, while in the other four porosity is not predicted. Nearly no difference was found between castings with rectangular or circular sections of the gating system.
From the real data it can be seen that the porosity level is high only in 10B-c and 10B-r (superior to 15%). In all the others it is lower, although not negligible. The most sound samples are 15D-c/r followed by 10A-c/r and 15C-c/r. Moreover, in the real situation, the rectangular running systems are better than the others.

CONCLUSIONS

The paper dealt with the study of the capacity of the Niyama criterion in predicting porosity in aluminium foundry. The predict values of Niyama criterion were compared with experimental results, in terms of percentage porosity in the cross section of the casting. The casting shape was quite elemental, consisting of a rectangular bar with different dimen-

sions and gate shape. In general a good agreement between the Niyama criterion and the experimental results could be found, since the criterion individuates the best and worst conditions.
However, the comparison shows some disagreement between the predictions, based on the Niyama function, and reality:
- the predictions underestimate the real values of the defects;
- the differences between rectangular and circular feeding systems were not predicted.

Like the other works present in literature, this experiment confirms the limit of the model as applied to aluminium. One major limitation, also noted by other authors, is not to consider the presence of gas in the liquid metal and not to reproduce accurately the mould filling, which in the present work led to an incorrect prediction of porosity.

ACKNOWLEDGEMENTS

The authors wish to thank the Fonderia Liotti (Ornavasso, VB) for their help in carrying out experimental work for the research presented in this article.

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ABSTRACT

STUDIO SULLA VALIDITÀ DELLA FUNZIONE CRITERIO DI NIYAMA APPLICATA ALLA LEGA A356

Parole chiave:
alluminio e leghe, solidificazione, fonderia

Con questo lavoro abbiamo voluto valutare l'efficacia della funzione criterio di Niyama nel predire lo sviluppo di porosità durante la solidificazione nella lega AlSi7Mg in processi di fonderia.
Attraverso l'utilizzo di un software di simulazione della solidificazione è stato ricavato il valore della funzione in esame in una geometria prescelta e poi confrontato con i valori sperimentali ottenuti in fonderia. Dal confronto tra simulazioni e dati sperimentali è emerso che il modello di Niyama, nell'ambito del lavoro svolto, non è un'efficace indice di valutazione dello sviluppo della porosità nella lega considerata.