ARCHIVES
of
FOUNDRY ENGINEERING
DOI: 10.1515/afe-2016-0043
Published quarterly as the organ of the Foundry Commission of the Polish Academy of Sciences
DE GRUYTER OPEN
ISSN (2299-2944)
Volume 16
Issue 3/2016
25 – 28

Quality Index of the AlSi7Mg0.3 Aluminium Casting Alloy Depending on the Heat Treatment Parameters

E. Czekaj [a], J. Zych [b], Z. Kwak [b], A. Garbacz-Klempka [b]*
[a] Foundry Research Institute, Zakopiańska 73 Str., 30-418 Kraków, Poland
[b] Department of Moulding Materials, Mould Technology and Cast Non-Ferrous Metals, Faculty of Foundry Engineering, AGH University of Science and Technology, Reymonta 23 Str., 30-059 Kraków, Poland
* Corresponding author. E-mail address: agarbacz@agh.edu.pl

Received 29.04.2016; accepted in revised form 05.07.2016

Abstract

Issues connected with high quality casting alloys are important for responsible construction elements working in hard conditions. Traditionally, the quality of aluminium casting alloy refers to such microstructure properties as the presence of inclusions and intermetallic phases or porosity. At present, in most cases, Quality index refers to the level of mechanical properties – especially strength parameters, e.g.: *UTS*, *YS, HB, E* (*Young's Modulus*), K_{1c} (stress intensity factor). Quality indexes are often presented as a function of density.
However, generally it is known, that operating durability of construction elements depends both on the strength and plastic of the material. Therefore, for several years now, in specialist literature, the concept of quality index (*QI*) was present, combines these two important qualities of construction material. The work presents the results of *QI* research for casting hypoeutectic silumin type EN AC-42100 (EN AC-AlSi7Mg0.3), depending on different variants of heat treatment, including jet cooling during solution treatment.

Keywords: Innovative foundry technologies and materials, Al-Si alloy, Quality index, Heat treatment, Jet cooling

1. Introduction

QI quality index plots are often used in the stage of construction elements design. They demand from the engineers to search alloys with certain mechanical properties complementary with their working conditions. Such responsible elements can be found in machine and automotive industry, as well as in aerospace and cosmonautics [1]. In the technical literature, both polish and international, it can be seen that strength and plastic properties of alloys are correlated [2-10].

The concept of quality index was first introduced in 1980 by Drouzy et al. [3], originally it was written as *Q* and defined in the following way (1):

$$QI = Q = UTS + d \cdot \log(A) \quad (1)$$

where: *UTS* – ultimate tensile strength; *A* – elongation at the moment of rupture of the sample; *d* – experimentally chosen coefficient *d,* depending on the alloy type (in the case of casting hypoeutectic silumins, the most often chosen value is 150 [9]).
Yield strength (*YS*) is related to ultimate tensile strength *(UTS)* by the relationship below (2):

$$YS = a \cdot UTS - b \cdot \log(A) - c \quad (2)$$

where: a, b and c are the coefficients determined on the basis of experimental data and they mainly depend on the type of alloy [10].

Quality Index Q is the function of tensile strength and plasticity of alloys, which can formally be written as (3):

$$Q = f(UST,\ A) \qquad (3)$$

Therefore, this equation can be interpreted as a set of connected mechanical properties reflecting the ability to use a given material for manufacturing responsible construction parts [11].

Further research in this field led to range of other proposed quality indexes for aluminum or magnesium alloys of (4) and (5) type [11]:

$$Q_0 = f(YS, W) = f(YS, UTS, A) \qquad (4)$$

$$Q_{0S} = f(YS, UTS, A, \rho) = f(YS, W, \rho) \qquad (5)$$

where: W is strain energy density, being the surface area under the stress-strain curve in the system: F (force) is the Δl strain (or in the system: stress σ – relative strain ε);
whereas $d\varepsilon = dl/l_0$, where $dl = \Delta l \rightarrow 0$, and l_0 – is the original length of the strength sample.

Strain energy density W can be established by integrating the area under the stress-strain curve in the $\sigma - \varepsilon$ system (layout), within the range of ε strain from 0 to $A_{max} = A$, from the following equation (6) [11, 12]:

$$W = \int_0^A \sigma d\varepsilon \qquad (6)$$

To determine the quality index of aluminum alloys additionally to the basic mechanical properties of researched materials identified by tensile tests (*UTS*, *YS*, *A* or *E*), Rockwell or Brinell hardness tests can also be used. In more advanced studies sometimes more complex energetic parameters describing their mechanical properties in the form of stress intensity factor K_{1c} or toughness *KCV*(U) in Charpy impact test are present. [2]

Because of the fact that a critical parameter in light constructions is their weight, similar as in the case of so called functionality indexes [12, 13], quality indexes are also expressed as a function of density ρ. These indexes are called specific indexes. [11].

The quality index is successfully used to compare the quality of aluminum casting alloys of different equilibrium (phase) systems [7], and for the same system – to compare the quality of alloys with differing amounts of alloying elements and impurities [5, 9]. *QI* assessment is also conducted, depending on the way of casting, applied purification procedures (modifying and/or refining), process characteristics and heat treatment parameters [6, 9].

Quality indexes and their derivatives can nowadays be commonly applied to assess comprehensively the operating durability of casting aluminum [14] and magnesium [11] alloys. This applies in the case of construction elements performing under changing(variable) mechanical loads.

The Al-Si alloys can be found in almost all traditional casting processes. Based on the studies conducted so far in the analysis of the properties of aluminum alloys recognizes a significant influence of the heat treatment methods and parameters on mechanical properties has been recognized. Casting hypoeutectic silumin type EN AC-42100 (EN AC-AlSi7Mg0.3) applied by the research group has equivalents in the world, among others, in the USA A356 [15], in GB LM25 [16] or in Japan AC4CH [17].

The issue of assessing the quality index of hypoeutectic silumins, depending on heat treatment parameters, have already been discussed in numerous publications. This paper presents a different perspective as it evaluates *QI* (*Q*) results depending on the cooling procedure during solution treatment, it is comparing the traditional cooling by submerging in water with an innovative way of jet cooling.

2. Test materials and methods

The tested material was cast hypoeutectic silumin EN AC-42100 (EN AC-AlSi7Mg0.3) type, with its chemical content presented in Table 1.

Table 1.
Chemical content of the experimental aluminum alloy EN AC-42000 (EN AC AlSiMg0.3) [18]

Origin	Chemical composition (%wt.)							
	Si	Cu	Mg	Mn	Fe	Zn	Ti	Sr
PN-EN 1706:2011	6,5÷ 7,5	≤ 0,05	0,25÷ 0,45	≤ 0,10	≤ 0,19	≤ 0,07	≤ 0,25	–
spectral analysis	7,01	0,01	0,28	0,02	0,13	0,01	0,09	0,03

The tested aluminum alloy was obtained In electric resistance furnace with a grog-graphite crucible, with 100 kg volume.

Strength test samples were cast in permanent mould heated to 200°C. The temperature of liquid metal during pouring reached 720-740°C.

Mechanical properties (*UTS*, *YS* and *A*) of the experimental alloy were, determined during the tensile strength test, at the room temperature, were tested at the following stages:

- F – as-cast,
- T5 – *as-cast* and artificially aged,
- T4 – solutionized and naturally aged (for few days),
- T6 – solutionized and artificially aged.

The research, consisted of two kinds of water cooling procedures during the solution treatment [18, 19, 20]:

- immersion cooling in water with temperature of 20°C, further marked as P

and

- spray cooling, with the micro-jet station (in water with temperature of 20°C), described in the paper [20] and marked as M.

The parameters of soaking the P and M samples before solution treatment were as follows: the temperature – 530°C; time – 2 h. During the micro-jet cooling, water from the pipe network was used, at the pressure of 4÷6 bars (5 bars on average).

Working with stages T5 and T6 three variants of artificial ageing were used:

S1 – at 155°C, for 10 h;
S2 – at 175°C, for 8 h;
S3 – at 205°C, for 6 h.

3. Results and Discussion

Table 2 collates the average measurement results of the basic mechanical properties (*UTS*, *YS* and *A*) at the room temperature, obtained from the tension test on the tension test machine EU-20 type. Based on that, using the (1) equation, the *QI* index values were calculated.

Table 2.
Measurement results of the basic mechanical properties and the *Q* index value results calculated from equation (1) for the experimental alloy o f AlSi7Mg0.3 type, depending on its treatment conditions

No.	Stage		*UTS*, [MPa]	*YS*, [MPa]	*A*, [%]	*QI(Q)*, [MPa]
	Abbreviation	Description				
1.	F	F	182	117	6,2	300,9
2.	T5	F + S1	197	135	3,2	272,8
3.	T5	F + S2	182	173	2,0	227,2
4.	T5	F + S3	212	145	5,6	324,2
5.	T4	P	227	115	15,0	403,4
6.	T6	P + S1	254	194	5,0	358,8
7.	T6	P + S2	270	218	6,5	391,9
8.	T6	P + S3	239	149	3,4	318,7
9.	T4	M	236	123	15,0	412,4
10.	T6	M + S1	249	187	5,1	355,1
11.	T6	M + S2	282	244	6,8	406,9
12.	T6	M + S3	235	200	5,0	339,8

F (as cast) and T5 stages with a variant of artificial ageing (S1, S2 or S3) give the lowest values of the quality index. The best *UTS*, *A* and Q results were obtained for F + S3 stage, this however, comes at the cost of lower yield strength (*YS*), with reference to the F + S2 stage.

The highest values of the quality index were observed for T4 stage; in the case of jet cooling they are slightly higher (*QI* = 412,4 MPa) compared to the immersion cooling (*QI* = 403,4 MPa).

For T6 stage similar values of the quality index, regardless of the cooling type during the solutionizing. For the samples aged in S1 way were established. In the case of S2 and S3 aging variants a higher value of mechanical properties and *QI* (*Q*) was observed for the case of jet cooling solutionizing (M). M + S2 variant showed the highest quality index value for stage T6 – at the level of 406,9 MPa.

On the basis of data from table 2 following figure (Fig. 1) was created. It shows the relationship between log*A* and *UTS* for AlSi7Mg0.3 alloy heat treatment in different ways. QI quality index levels of 200 to 450 MPa are also listed.

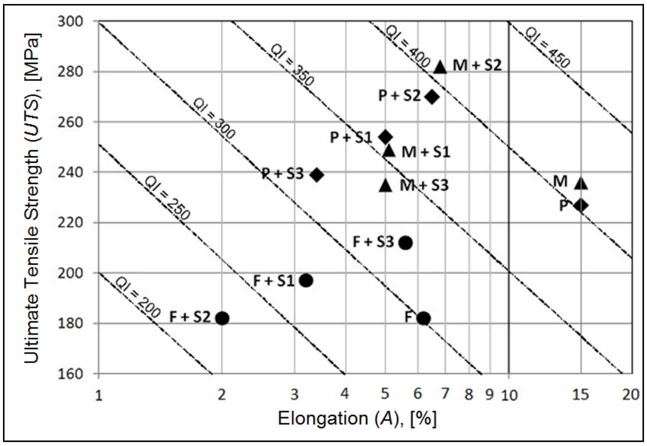

Fig. 1. Relationship between log A (Elongation) and UTS (Ultimate Tensile Strength) for different variants of heat treatment

The data from Table 2 made it possible to prepare one more interesting comparison (Fig. 2), ranking the data from the highest to the lowest value.

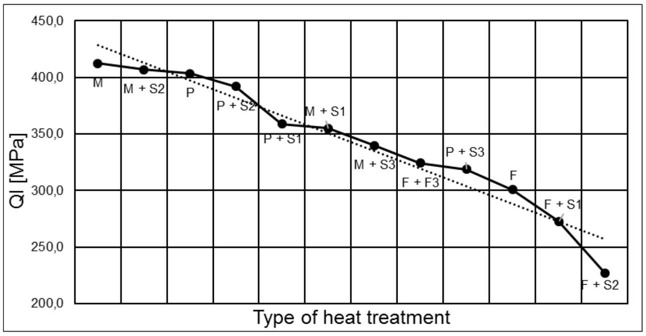

Fig. 2. Ranking of the heat treatment for AlSi7Mg0.3 with use of Quality Index (based on the data of Table 2)

The diagrams in Figs. 1 and 2 allow to easily observe some regularities in modifying the quality of the AlSi7Mg0.3 cast alloy, depending on the type of cooling procedure applied after solution heat treatment (P or M) and the type of artificial ageing that was chosen. (S1, S2 or S3).

4. Conclusions

Mikro-jet cooling of AlSi7Mg0.3 alloy elevated the mechanical properties and quality index *QI* also slightly.

The conducted research allows to conclude that both the stage of alloy (F, T4, T5 and T6) as well as the type of cooling procedure during the quenching (P or M) influences the values of mechanical properties (*UTS*, *YS* and *A*) and consequently, the values of the quality index *QI* (*Q*).

Obtained results could be explained by the relatively low water pressure of the jet cooling appliance (about 5 bar). This did not permit complete penetration of the water micro-jets to the sample surface because a so called 'cushion' of water steam, that was created.

Acknowledgements

This article was conducted within the project of: INNOLOT /I/10/NCBiR/2014– Innogeart.

References

[1] Knych, T., Uliasz P., Wiecheć J. & Podeszwa K. (2014). Research on the Selection of Parameters of Solution Heat Treatment of the Commercial Casting Aluminium Alloy AlSi7Mg0.3 Type. *Archives of Foundry Engineering.* 14(special 4), 59-62.

[2] Alexopoulos, N.D. & Pantelakis, S.G. (2004). Quality Assessment of Artificially Aged A357 Aluminum Alloys Cast Ingots by Introducing Approximate Expressions of the Quality Index Q_D. *Metallurgical and Materials Transactions A*. 35A(10), 3079-3089.

[3] Drouzy, M., Jacob, S. & Richard, M. (1980). Interpretation of Tensile Results by Means of Quality Index and Probable Yield Strength. *AFS Int. Cast Met. J.* 5(2), 43-50.

[4] Din, T., Rashid, A. & Campbell, J. (1996). High Strength Aerospace Casting Alloys: Quality Factor Assessment. M*aterials Science and Technology.* 12, 269-273.

[5] Alexopoulos, N.D. & Pantelakis, S.G. (2003). Evaluation of the Effects of Variations in Chemical Composition on the Quality of Al-Si-Mg, Al-Cu, and Al-Zn-Mg Cast Aluminum. *Journal of Materials Engineering Performance*. 12(2), 196-205.

[6] Alexopoulos, N. D. & Pantelakis, S. G. (2004). Quality evaluation of A357 cast aluminum alloy specimens subjected to different artificial aging treatment. *Materials & Design Journal.* (25), 419-430.

[7] Alexopoulos, N. D. & Pantelakis S.G. (2004). Quality assessment of artificially aged A357 aluminum alloy cast ingots by introducing approximate expressions of the quality index Q D. *Metallurgical and Materials Transactions A.* 35(10), 3079-3089.

[8] Jacob, S. (1999). Quality Index in the Prediction of Properties of Aluminum Castings. *AFS Transactions, Silver Anniversary paper*. 107, 811-818.

[9] Orłowicz, A.W. & Mróz, M. (2004). Indicator of the quality of castings from Al-Si alloy. *Archives of Foundry.* 4(14), 363-368. (in Polish).

[10] Mohamed, A., Fawzy S. (2010). *Performance of Aluminum-Silicon Cast Alloys.* Saabrücken: LAP LAMBERT Academic Publishing GmbH & Co. KG (in Germany).

[11] Pantelakis, S.G, Alexopoulos, N.D & Chamos, A.N. (2007). Mechanical performance evaluation of cast magnesium alloys for automotive and aeronautical applications. *Journal of Engineering Materials and Technology, Transactions of the ASME.* 129(3), 422-430.

[12] Ashby, M., Shercliff, H., Cebon, D. (2011). *Material Engineering*. Tom 1 i 2. Łódź: Wydawnictwo GALAKTYKA. (in Polish).

[13] Pysz, S., Czekaj, E., Żuczek, R., Maj, M. & Piekło J. (2016). Low Cycle Mechanical and Fatigue Properties of AlZnMgCu Alloy. *Archives of Foundry Engineering*. 16(1), 55-60.

[14] Anon „Advanced Aluminum Precision Casting For Integrally Stiffened Net-Shape Components (ADVACAST). Final Technical Report of the BRITE Project 4084, Brussels, Belgium, 1996.

[15] ASTM 108/B108M-12: Standard Specification for Aluminium-Alloy Permanent Mold Castings.

[16] JIS H 5202:2010. Aluminium alloy castings. Japanise Industrial Standarts Committee.

[17] BS 1490-1988: Specification for aluminium and aluminium alloy ingots and castings for general engineering purposes.

[18] PN EN-1706:2011 Aluminium and its alloys. Castings. The chemical composition and mechanical properties. (in Polish).

[19] Ambos, E., Besser, W., Honsel, W., Schulze, M. & Franz P.Ch. (2011). JetCooling – Arbeitsweise, Wirkung und Ergebnisse. *Giesserei-Rundschau.* 58, 57-61.

[20] Górny, Z., Kluska-Nawarecka, S., Czekaj, E., & Saja, K. (2011). Aplication of microjet in heat treatment of aluminium bronzes. *Archives of Foundry Engineering*. 11(2), 35-40.