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Reduction of the heat treatment process for Al-based alloys by utilization of heat from the solidification process

X. Chen, W. Kasprzak, J.H. Sokolowski *

Light Metals Casting Group in the Department of Mechanical, Automotive and Materials Engineering at the University of Windsor, Room 212A, Essex Hall, 401 Sunset Avenue, Windsor, Ont., Canada N9B 3P4

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Abstract

This paper presents the results for reduction of the heat treatment process duration by way of a solution treatment integrated with the solidification process as an economical heat treatment for aluminum-based castings. The so-called "novel solution treatment during the solidification process" (NSTS) uses some heat from the solidification process. In turn, this would reduce production costs. The effect of the NSTS process on the structure and mechanical properties of the 319 alloy has been investigated. The results from this study were compared with the well-established conventional solution heat treatment process (CST). Comparison studies showed that the NSTS process results in similar or even higher mechanical properties than the conventional solution treatment process. It was found that the NSTS at 510 °C for 30 min delivered the maximum metal matrix microhardness (i.e., 112 ± 4.4 HV25) and the required level of Cu-enriched phases dissolution. The NSTS process for the 319 alloy performed at 510 °C for 30 min gives a UTS of approximately 202 and 240 MPa for 2 weeks of natural aging and artificial aging at 200 °C for 2 h, respectively. The total cycle time for the NSTS process is approximately two times shorter than for the conventional solution treatment process which might be a significant economical advantage.

To meet the industrial requirements the NSTS process could be modified by cooling the casting a few degrees below the solidus temperature (after completion of the solidification process) and by then reheating it to the required solution treatment temperature. As a consequence the heat treatment operation can be done in a continuous manner, utilizing a considerable amount of heat from the solidification process. Preliminary results indicate that the casting temperature, prior to entering the solution treatment furnace, influences the castings' response to the heat treatment operation.

Keywords: 319 Foundry alloy; Solidification process; Metallurgical simulations; Heat treatment; Thermal analysis; Mechanical testing

1. Introduction

319 Aluminum alloy has been successfully used in the automotive industry as a material for engine blocks and cylinder heads. In order to improve the mechanical properties of these components they are often heat treated using a two-step process (i.e. solution treatment and artificial aging). Two important solution treatment process variables are time and temperature. They are responsible for Si particle modification and for the dissolution of Cu- and Mg-enriched phases [1,12,15–17]. For sand casting the solution treatment can be combined with thermal sand removal as one continuous operation. High energy costs and competitiveness in the automotive market have forced foundries to redesign production processes in order to make them more energy efficient and economical. Unfortunately, the existing heat treatment standards that are available to the metal casting community, do not reflect the continuously changing economy which is driven by cost reduction.

Research centres have focused on reducing the heat treatment process duration while maintaining similar or even higher mechanical properties for light alloy components. For years this issue has been a concern for the ferrous alloy industry, reflected by numerous studies regarding alloy chemistry and thermal processing optimization [5,13].

Scientific research has been done on the effect of a short solution treatment time (less than 30 min) on the microstructure and properties of fully modified Al–Si–Mg alloys [17]. Interest has been generated in the practice of using solidification heat derived from areas other than the work piece portion of the casting to perform further heat treatment operations. For example,

* Corresponding author. Tel.: +1 519 253 3000x3588; fax: +1 519 561 1405.
E-mail address: jerry@uwindsor.ca (J.H. Sokolowski).

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heat accumulated in the casting riser can be utilized for further artificial aging. Some work has been done to interrupt the solidification process at a given temperature through the quenching operation followed by the artificial aging process [7,14].

Recently the authors have focused on combining the solidification process with the heat treatment process into one continuous operation. This research is intended to explain the metallurgical phenomena behind the novel solution treatment during the solidification process (NSTS) [2,8,9]. This research will help to design the novel economical thermal processes that will fully take advantage of the alloy chemistry and the achievable mechanical properties.

The goal of this paper is to present some metallurgical aspects of the novel economical heat treatment for aluminum castings that uses the heat from the solidification process. The effect on the structure and mechanical properties of the 319 alloy in comparison with the conventional solution treatment is investigated. Moreover, selected alternatives are presented that might be suitable for industrial applications.

2. Materials and experiments

The laboratory experiments were performed using pre-machined cylindrical test samples with a diameter of $\varphi = 16$ mm and a length of $l = 18$ mm. The analyzed test samples were machined from an unmodified 319 alloy (Table 1). These samples were used for heat treatment simulations and for thermal analysis (TA). Selected heat treatment processes were performed for the test samples with a diameter of $\varphi = 50$ mm and a length of $l = 150$ mm. The test cup equipped with a riser was designed to ensure directional solidification with a cooling rate of approximately 0.2 °C/s. Four (4) tensile test bars from each test sample were then machined for further mechanical testing.

Table 1
Chemical composition of the investigated 319 aluminum alloy

Average Composition, wt %										
Si	Cu	Fe	Mg	Mn	Zn	Ti	Sr	Ni	Sn	Pb
7.70	3.38	0.38	0.27	0.23	0.08	0.12	0.0007	0.018	0.0033	0.012

The advanced heat treatment simulations and thermal analysis were performed using the universal metallurgical simulator and analyzer (UMSA) [10]. This system allows the user to perform complex simulations of the melting/solidification processes and various heat treatments in a continuous or interrupted manner with very precise temperature control.

Thermal analysis was performed in order to identify the metallurgical reactions during the melting and solidification cycles [4,11]. The results from the thermal analysis of the solidification process were not used for the development of the optimum solution treatment operation due to the thermal histeresis effect that is observed as a shift between the melting and solidification cycle(s) characteristic temperatures.

Therefore, the data from the melting (heating) cycle was utilized for the design of the solution treatment operation.

The 319 alloy test samples were subjected to the conventional solution treatment from 500 to 540 °C with a 10 °C step for 30, 60, 120 and 240 min, followed by air quenching at a cooling rate of approximately 1 °C/s and 2 weeks of natural aging at room temperature (Fig. 1a). Selected test samples were subjected to artificial aging at 200 °C for 2 h (Fig. 1b).

The incipient melting temperature was purposely exceeded for the conventional solution treatment at 520, 530 and 540 °C. This was done in order to create similar conditions for the NSTS process and to provide the basis for comparison of the effectiveness of both heat treatment processes. The heating rate to the solution temperature for the conventional heat treatment process was approximately 0.2 °C/s.

The NSTS process was performed from 500 to 540 °C with a 10 °C step for 30, 60, 120 and 240 min followed by air quenching at a cooling rate of

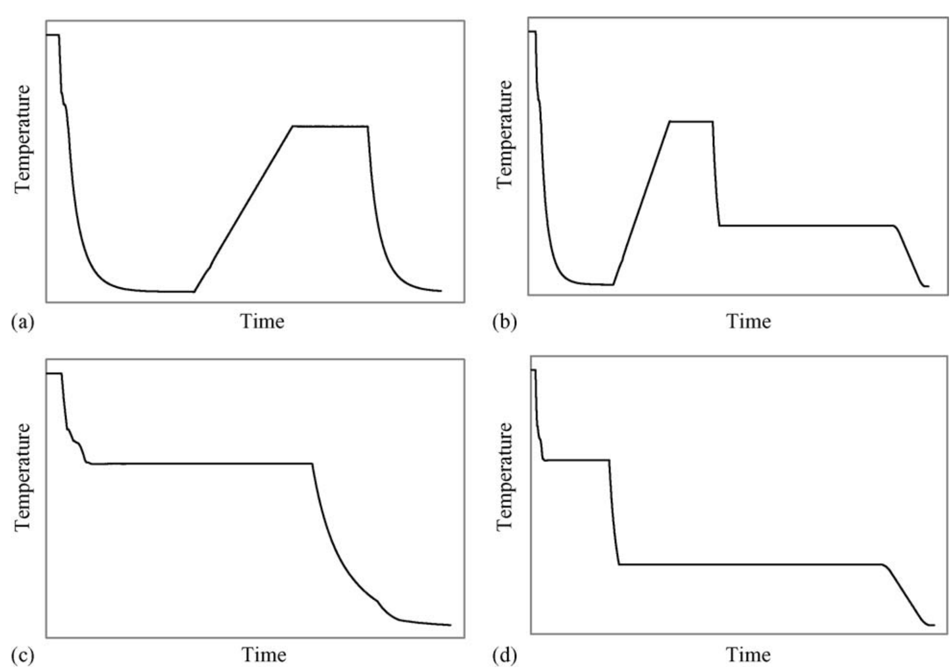

Fig. 1. Schematic temperature vs. time plots of the thermal cycles performed for the investigated 319 alloy. (a) Solidification followed by the conventional solution treatment (CST) and air quenching. Next the test sample was subjected to 2 weeks of natural aging at room temperature. (b) Solidification followed by conventional solution treatment (CST), air quenching and continuous artificial aging. (c) The novel solution treatment during the solidification process (NSTS) followed by air quenching. Next the test sample was subjected to 2 weeks of natural aging at room temperature. (d) Novel solution treatment during the solidification process (NSTS) followed by air quenching and artificial aging. Note: the NSTS and CTS temperature and time were optimized.