POLISH ACADEMY OF SCIENCES - MATERIALS SCIENCE COMMITTEE
SILESIAN UNIVERSITY OF TECHNOLOGY OF GLIWICE
INSTITUTE OF ENGINEERING MATERIALS AND BIOMATERIALS
ASSOCIATION OF ALUMNI OF SILESIAN UNIVERSITY OF TECHNOLOGY
Conference Proceedings
11th INTERNATIONAL SCIENTIFIC CONFERENCE
ACHIEVEMENTS IN MECHANICAL & MATERIALS ENGINEERING

The effect of the solidification shrinkage and heat treatment process on the structural damage of the interface between of the 319 alloy and cast iron

L.A. Dobrzański[b], W. Kasprzak[a,b], J.H. Sokolowski[a]

[a]NSERC/Ford-NEMAK/ University of Windsor Industrial Research Chair in Light Metals Casting Technology, 401 Sunset Ave., Windsor, Ontario, Canada, N9B 3P4

[b]Institute of Engineering Materials and Biomaterials, Silesian University of Technology Konarskiego St. No 18a, 44-100 Gliwice, Poland

This paper presents the effect of the solidification shrinkage and heat treatment process on the development, as well as the structural damage of the interface between the 319 alloy test sample and cast in iron insert. It was found that during the solidification process, the difference in the thermal contraction coefficient between the 319 alloy and cast iron, creates stress on the interface, which leads to its macro cracking. The Crack Density found on the interface is lower for the test sample subjected to the continuous heat treatment process. The simulation results can be used to develop a stress model for an automotive component made from an aluminum based alloy with iron inserts.

1. INTRODUCTION

The way in which aluminum alloy melts are processed and the manner in which cast components are heat treated, influence their metallurgical structures and ultimately their mechanical properties [1-7]. An important goal of aluminum casting research is to simulate the solidification processes of production castings in the laboratory. Unfortunately, automotive foundry production occurs on a scale that makes laboratory simulation difficult. Recently, automotive foundries have become more aware of rising energy costs. This has prompted companies to redesign production processes in order to make them more energy efficient [5-7]. Special attention is being paid to aluminum based alloy components with cast in iron inserts. Dissimilarity of the materials having different thermal expansion / contraction coefficients leads to the development of excessive stresses during manufacturing. Therefore, factors like alloy chemical composition, cooling rate during the solidification process and heat treatment parameters have to be tailored for specific production processes.

The goal of this paper is to present the laboratory simulation of the development of the structural damage of a test sample composed of two dissimilar materials, during solidification and when subjected to variable heat treatment processes.

2. EXPERIMENTAL PROCEDURES

The experiments were carried out using cylindrical specimens (φ = 16mm and l = 15mm) machined from a 319 casting (~7%Si, ~3%Cu, Al - balance). Additionally, cylindrical inserts machined from ductile cast iron (φ = 10mm and l = 15mm), were inserted into the 319 samples having a predrilled hole of 10mm in diameter. The solidification simulations and Thermal Analysis were performed using the Universal Metallurgical Simulator and Analyzer (UMSA) [7,9]. UMSA combines a sophisticated melting and heat treatment “furnace”, with a quenching station and a Thermal Analysis apparatus [4]. Additionally, the 319 aluminum alloy test samples with cast iron inserts were subjected to solution treatment at 495^{o}C for 90 minutes, followed by natural cooling to room temperature. For the remainder of this paper, this process is referred to as the “Interrupted Process”. The solution treatment temperature of 495^{o}C was selected in order to avoid the incipient melting of Cu based phases. For comparison purposes, the isothermal holding during the solidification process was performed at 495^{o}C for 90 minutes (hereinafter referred to as the “Continuous Process”). Classical metallurgical analysis (LOM, SEM, Image Analysis, Microhardness etc.) of the test samples subjected to the various processes was carried out following the experiments [5,6].

3. RESULTS

Thermal Analysis for the 319 alloy test sample revealed that three main metallurgical reactions can be recognized during the solidification process: the nucleation of the Al dendrite network - 598.4^{o}C, the nucleation of the Al-Si eutectic phase - 562.7^{o}C and the nucleation of the Cu enriched phases - 495.3^{o}C [5,6]. The incipient melting of the copper enriched phases during heating will occur when the temperature exceeds 497^{o}C. Therefore, for the given experimental conditions, the one-step solution treatment should not exceed this temperature [5-7]. The Thermal Analysis performed during the heating and cooling process of the 319 test sample with the 10mm ductile cast iron insert showed negligible differences in the cooling rate recorded by the temperature sensor placed in the 319 alloy and in the cast iron insert [6]. The SEM observations of the cross-section of the test samples subjected to further heat treatments showed that numerous microcracks developed on the interface between the 319 alloy and the cast iron insert (Figure 1). It is believed that the cracks developed during the solidification process and were also extended during the additional solution treatment for test samples subjected to the "Interrupted Process". The reason for this is that the 319 alloy thermal expansion coefficient is approx. 2 times higher than for cast iron. Additionally, SEM observations revealed the interface layer between the 319 alloy and the cast iron insert (Figure 2). The X-ray microanalysis determined that the layer is composed of O, Al, Si, Mn and Fe. It is believed that it was created during the test sample solidification, due to the interaction between the liquid 319 alloy and the cast iron insert. The layer was heavily cracked, due to the presence of stresses which developed during solidification and as a result of further heat treatment (Figure 2).

The microhardness measurements of the test sample with the 10mm ductile cast iron insert showed that the isothermal holding during solidification at 495^{o}C for 90 minutes ("Continuous Process"), increased the aluminum matrix microhardness to 106HV25. This is approximately 5% more compared with the “Interrupted Process” (Figure 3) and about 26% more than compared with the as-cast material [5, 6].

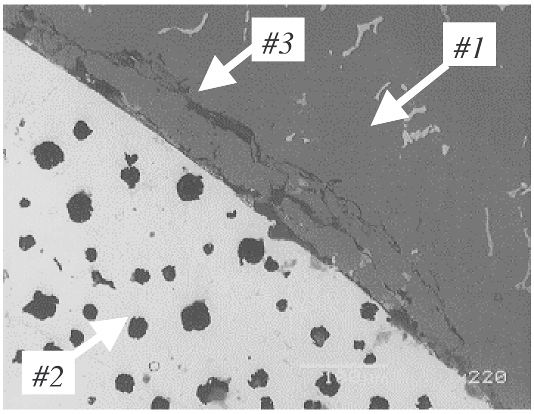

Figure 1. Scanning Electron Microscopy (SEM) micrograph (BSE image) of the 319 alloy test sample (#1) and the cast iron (#2) interface with numerous micro cracks which (#3) developed during solidification of the test sample due to the differences in thermal contraction (220x).

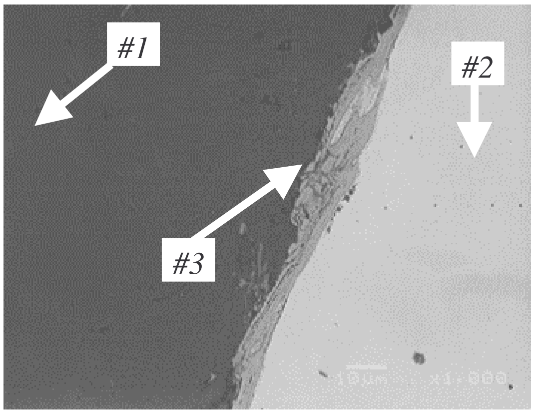

Figure 2. Scanning Electron Microscopy (SEM) micrograph (BSE image) of the 319 alloy test sample (#1) and the cast iron (#2) interface with the iron rich layer (#3) which developed during solidification. Note that the layer is heavily cracked (1000x).

The Image Analysis results showed that the test sample subjected to isothermal holding during the solidification process ("Continuous Process") had a lower Crack Density than the test sample subjected to the “Interrupted Process”. The number of cracks found on the interface can be correlated with the metal matrix microhardness. Test samples with higher hardness i.e., 106HV25, subjected to the “Continuous Process”, had a 10% lower Crack Density (i.e., 1.7) than for the “Interrupted Process” (Figure 3). It is believed that matrix microhardness is not the only metallurgical factor influencing the ability of the test sample to sustain the stress created due to thermal expansion / contraction coefficient differences between the 319 alloy and cast iron. The morphology of the structural constituents, like Si and Cu based phases, which are affected by the heat treatment, have to be considered as well. Under given stress conditions, caused by the thermal expansion / contraction differences between dissimilar materials these could become the crack nucleation sites. The decohesion between structural constituents and metal matrix, under a given stress level, could be extended by the linking process. This can lead to rapid fracture through the metal matrix [6].

4. CONCLUSIONS

The analysis of structural damage to the test sample, composed of two dissimilar materials, showed that the Crack Density on the interface is lower for the test sample subjected to the “Continuous Process”. This process obtains a matrix microhardness 5% higher than for the “Interrupted Process”. The total cycle time for the “Continuous Process” is about 40% shorter than for the “Interrupted Process". The number of cracks can be correlated with the metal matrix microhardness. The combination of strength and ductility of the metal matrix and morphology of the structural constituents must be analyzed in order to understand the ability of the material to sustain stress. The information presented above, if complemented by

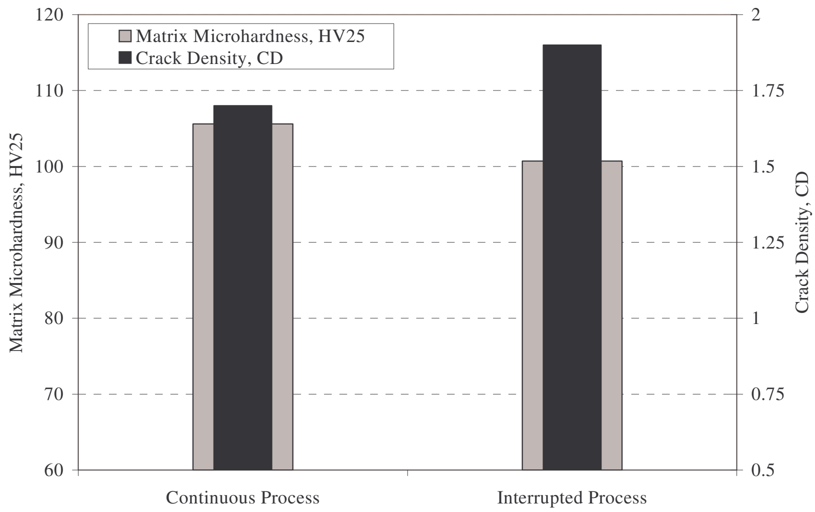

Figure 3. The Vickers microhardness (HV25) of the aluminum matrix and density of cracks (CD) found on the 319 alloy / cast iron insert interface for the test samples subjected to isothermal holding during the solidification process at 495°C for 90 minutes ("Continuous Process") and solution treated at 495°C for 90 minutes ("Interrupted Process").

REFERENCES

1. L. Bäckerud, G. Chai and J. Tamminen: Solidification Characteristics of Aluminum Alloys, (Oslo, AFS /Skanaluminium, 1986), 1-3.
2. J.R. Davis ed.: ASM Specialty Handbook: Aluminum and Aluminum Alloys, (ASM International, 1993).
3. M.B. Djurdjevic, W. Kasprzak, C.A. Kierkus, W.T. Kierkus and J.H. Sokolowski: "Quantification of Cu Enriched Phases in Synthetic 3XX Aluminum Alloys Using the Thermal Analysis Technique", 105th Casting Congress, Dallas, USA, 2001.
4. M. Kasprzak, W. Kasprzak, W.T. Kierkus and J. H.Sokolowski: "Universal Metallurgical Simulator and Analyzer (UMSA)", US Patent Pending, 2001.
5. M. Kasprzak, W. Kasprzak, C.A. Kierkus, W.T. Kierkus, J.H. Sokolowski and W.J. Evans:, "The Structure and Matrix Microhardness of the 319 Aluminum Alloy After Isothermal Holding During the Solidification Process", 105th Casting Congress, Dallas, USA, 2001.
6. M. Kasprzak, W. Kasprzak, C.A. Kierkus, W.T. Kierkus and J.H. Sokolowski: Applications of High Frequency Induction Heating for the Metallurgical Simulation and Thermal Analysis of Industrial Light Metals Casting Processes, Proceedings of TMS (The Minerals & Materials Society), 131st TMS Annual Meeting, Seattle, Washington, USA, February 17-21 2002, pp. 619-630.
7. J.H. Sokolowski, M.B. Djurdjevic, C.A. Kierkus and D.O. Northwood: "Improvement of 319 Aluminum Alloy Casting Durability by High Temperature Solution Treatment", Journal of Advanced Materials Processing Technology, in press.