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Analysis of the Al-Si Alloy Structure Development using Thermal Analysis and Rapid Quenching Techniques

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This paper presents analysis of the structure development of the Al-Si alloy during the solidification process using thermal analysis and rapid quenching techniques. Quenching experiments during the alloy solidification process were performed a few degrees below the temperatures of the main metallurgical reactions. Structure analysis revealed which phases were already present at given quenching temperatures and which will progress further. This information was correlated with the fraction solid calculation based on thermal analysis and image analysis techniques.

1. INTRODUCTION

In order to effectively control microstructure development during the melting, solidification as well as further materials processing (like heat treatment, thermo-mechanical treatment, etc.) it is necessary to understand all metallurgical phenomena taking place. Knowledge of the solidification process as well as the influence of liquid and/or semi solid metal treatment (by chemical, thermal and mechanical means) on micro and macro structure characteristics is of primary importance. Control of the structural constituent's morphology, formation of undesirable phases during the solidification process as well as dissolution during subsequent heat treatment processes must be evaluated in detail [1,3-5].

Advanced thermal analysis combined with on line quenching capabilities is a suitable technique because it allows for simultaneous monitoring of the structure evolution based on the temperature–time signal supported by the structural post evaluation of the test samples quenched from precisely defined temperatures [2].

The goal of this paper is to present laboratory analysis of the structure development of the W319 alloy during the solidification process using thermal analysis and quenching techniques.

2. EXPERIMENTAL PROCEDURES

The laboratory experiments were performed using cylindrical specimens with a diameter of φ = 16mm and a length l = 18mm. All test samples were machined from an unmodified W319 alloy (~7%Si, ~3%Cu, Al - balance). This alloy is used successfully by the automotive industry. The advanced thermal analysis and quenching operations were performed using the Universal Metallurgical Simulator and Analyzer (UMSA) [2]. Advanced thermal analysis was done in order to identify the metallurgical reactions during the melting and solidification cycles. The test samples were solidified under identical conditions until they exceeded the nucleation temperature of specific reactions by a few degrees at which time they were rapidly quenched. The test samples were equipped with highly sensitive thermocouples and the temperature vs. time history of each quenching cycle was recorded and analyzed after completion of the experiments. The salt/water solution was used as a quenching medium. The same test samples were analyzed using Light Optical Microscopy (LOM) combined with Image Analysis (IA) and Scanning Electron Microscopy (SEM/EDX).

3. RESULTS

Light Optical Microscope (LOM) observations of the as cast sample solidified at a cooling rate of 0.75^{o}C/s showed an unmodified microstructure consisting of the aluminum based matrix, Al-Si and Al-Cu eutectics and Fe enriched phases [1-3]. Due to the complexity of the Al-Cu eutectic the authors will use the term Cu enriched phases. In the W319 alloy the Cu enriched phases have three main morphologies namely blocky, eutectic and fine eutectic.

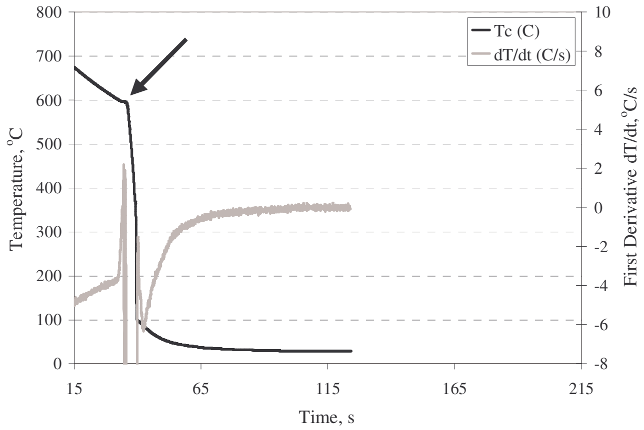

Figure 1. The cooling curve (black) and its First Derivative (gray) of the W319 alloy test sample rapidly quenched from below the nucleation point of the Al dendrite network, i.e., 594^{o}C (pointed out by the arrow).

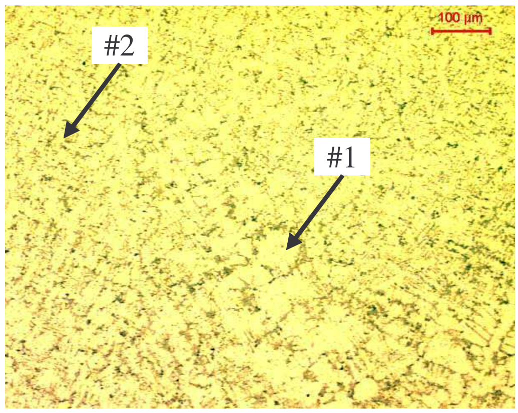

Figure 2. LOM micrograph (100x) of the rapidly quenched test sample structure at 594^{o}C. (#1) - Al dendrites developed between liquidus and quenching temperatures, (#2) - Fine dendrites that represent pools of liquid alloy that exist just prior to quenching.

Nucleation and dissolution temperatures of the Cu enriched phases depend on the chemistry as well as on the morphology [1]. Thermal Analysis (TA) confirmed the structure observations, revealing that there were three main metallurgical reactions during the solidification process: the nucleation of the Al dendrite network at 603^{o}C, the nucleation of the Al-Si eutectic phase at 568^{o}C and the beginning of nucleation of the Cu enriched phases at 501^{o}C.

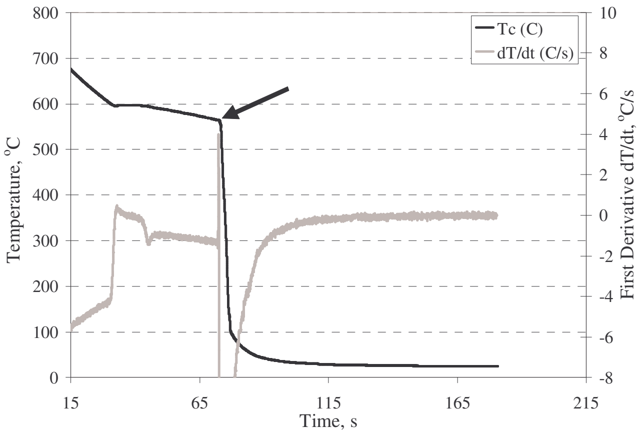

Figure 3. The cooling curve (black) and its First Derivative (gray) of the W319 alloy test sample rapidly quenched from below the nucleation point of the Al-Si eutectic, i.e., 560°C (pointed out by the arrow).

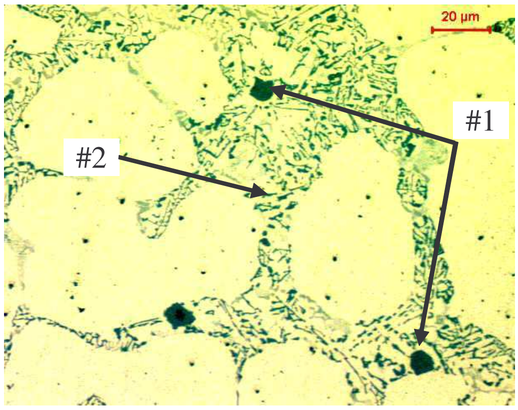

Figure 4. LOM micrograph (500x) of the rapidly quenched test sample structure at 560°C. (#1) - Polyhedral Si crystals, (#2) - pools of liquid alloy that exist just prior to quenching.

The test sample rapidly quenched at 594°C (Figure 1) shows very fine dendrites developing between the liquidus and quenching temperatures (Figure 2, arrow #1). The microscopic pools of liquid alloy that exist prior to the quenching operation had an ultra fine dendritic morphology (Figure 2, arrow #2). The Secondary Dendrite Arm Spacing (SDAS) measured for the quenched microstructure was approximately 10.5±2.3µm compared with 49.9±2.6µm for the microstructure solidified under natural heat exchange conditions (i.e., 0.75°C/s solidification rate). The Fraction Solid (FS) at the quenching temperature, i.e. 594°C, is calculated based on the thermal analysis results and is approximately 14%.

The thermal analysis results and structural observations for the test samples rapidly quenched below the nucleation point of the Al-Si eutectic are presented in Figures 3 and 4.

The test samples rapidly quenched below the nucleation point of the Cu enriched phases i.e., 493°C (Figure 5) show the Cu enriched phases that have developed between the liquidus and quenching temperatures (Figure 6, arrow #1). Moreover fine Cu enriched phases with very fine dendritic structures were found (Figure 6, arrow #2). They represent the microscopic pools of liquid that exist just prior to the quenching operation. The Fraction Solid (FS) at the quenching temperature, i.e. 493°C, is calculated based on the thermal analysis results and is approximately 98%.

4. CONCLUSIONS

The results presented highlight an approach that can control the solidification process and all accompanying metallurgical phenomena by setting up a direct link between the thermal analysis signal and its corresponding structural constituent(s). Moreover the concept can be applied during the alloy melting process (quenching can be done during the heating cycles).

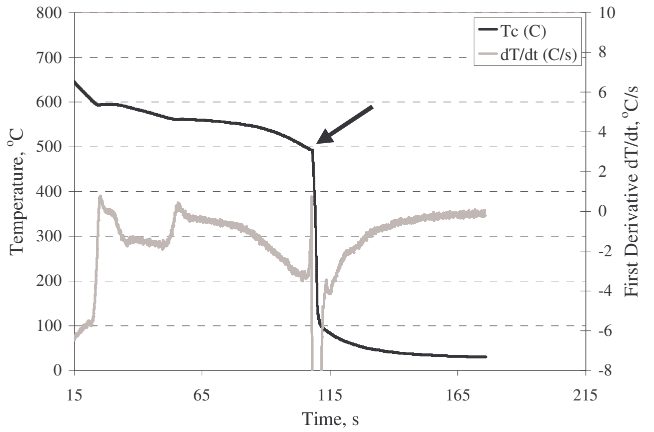

Figure 5. The cooling curve (black) and its First Derivative (gray) of the W319 alloy test sample rapidly quenched from below the nucleation point of the Cu enriched phase, i.e., 493°C/s (pointed out by the arrow).

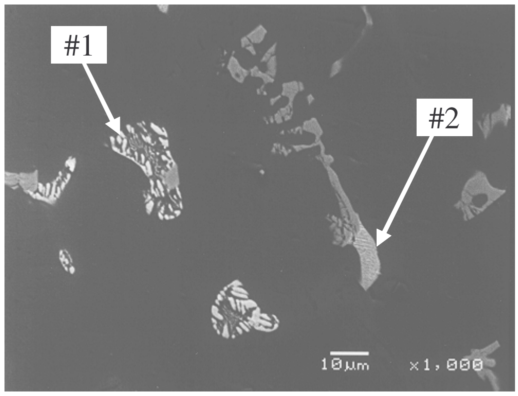

Figure 6. SEM/BSE micrograph (1000x) of the test sample rapidly quenched from 493°C. (#1) - Cu enriched phases that developed between the liquidus and quenching temperatures, (#2) - Cu enriched phases that represent pools of liquid alloy that exist just prior to quenching.

In turn, from the practitioner's point of view this will help to design the novel accelerated thermal processes that will fully take advantage of the alloy composition and the achievable mechanical properties for a given chemistry and for specific application(s).

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