Research Programs

Optimization of the Heat Treatment of Semi Solid Processed A356 Aluminum Alloy

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Abstract

This research investigates the relationship between T5 heat treatment and elongation in thixocast and rheocast SSM components as a means to reduce the energy, time, and cost associated with T6 treatments while still producing improved properties over the as-cast condition. Temperature and time are varied as a part of work to optimize aging conditions for SSM materials. Both conventional furnace and fluidized bed heat treatments are employed. Tensile bars are fabricated from the heat treated A356 components and pulled. Extensive SEM and stereo microscopy are performed to examine the factors which produced favorable results in the T5 condition. Data generated for T6 and as-cast components are collected for purposes of comparison. Quality index calculations are employed to help evaluate the results. Optimized procedures and aging parameters are presented.

Introduction

Since the bronze age, casting techniques have involved liquid melt processing in one fashion or another. Very recently, however, a new technique has been introduced. Due to the differences in thermal history and rheological character between semi solid material and liquid metal, the necessary processing steps are not the same as they have been for thousands of years of foundry experience. The intuition of foundrymen, developed as the trade itself did over the millennia, is not necessarily correct when it comes to semi solid metallurgy.

Although knowledge of the mechanisms behind heat treatment of metals is not nearly as old as metal casting itself, those mechanisms have been understood for almost 100 years. As with all new processes, after the mechanisms for SSM heat treatment were commercialized, the first heat treatments applied to it were essentially those already in use for dendritic materials. These treatment regimes are not necessarily the optimal ones, as the differing microstructure and solidification history of SSM components changes a number of factors. There were also questions about the relative merits of T5 (artifical aging) and T6 (solutionizing, quenching, and aging) treatments for SSM components. Some felt that there was a reduction of the high as-cast ductility during T5 treatments, while others disagreed. This work sought to remedy that situation situation.

Objectives

- The primary objective of this research was to examine the potential for low cost/time/energy heat treatments for aluminum A356 SSM components.

- Establishing whether or not the high as-cast (F) ductility could be retained, as suggested, in artificial aging (T5) heat treatments was an important aspect of this objective.
    - If the retention of as-cast ductility proved to be a real phenomenon, it would be important to establish the mechanism by which it operates.
    - Establishing the tensile properties of as-cast, T5, and T6 components was also related to the primary objective.
    - Fluid bed heat treatments also have the potential for improved aging efficiency, and were investigated as a part of this work towards those ends.
- Since thixocasting components are going out of fashion with many casters and rheocasting methods are continuing to develop, one objective of this work was to establish whether thixocast and rheocast components heat treat in the same manner.
- Temperature and time requirements for optimal tensile properties as well as operational windows were established.
- Although not an objective when this work began, it quickly became apparent that establishing the sensitivity of the experiment to variations of various experimental parameters was an important objective.

Strategy

- Selection of alloy(s) and procurement of SSM castings from different companies with the help of our consortium members.
    1. Vary solutionizing temperature,
    2. Vary aging temperature,
    3. Vary solution time,
    4. Vary aging time,
    5. Vary heat treatment method (Conventional Furnace and Fluidized Bed),
    6. Vary material processing condition, (SSM, both thixocast and rheocast)
- Conduct T5 and T6 heat treatments of A356 components while:
- Compare existing squeeze cast and conventionally cast material results
- Conduct ASTM E8-98 tensile testing; specifically:
    1. ASTM tensile bars were machined from the heat treated materials and tensile tests will be performed. Ten (10) bars will be tested per HT condition.
    2. All samples were robotically machined to insure uniformity
    3. 100% fracture analysis was employed to separate the effects of oxides and porosity from those of the base material.
    4. Quality Index calculations were employed to normalize variations due to chemical differences.
- A variety of microstructural and chemical analysis methods were used to analyze the heat treated samples to discern the underlying mechanisms behind the unique SSM heat treatment opportunities. Methods included:
    1. Microscopy using SEM with EDX
    2. Optical microscopy, including deep etching
    3. Spark analysis to investigate the chemical makeup of samples coupled with Pandat software to explore differences in solidification behavior between samples
    4. Thermodynamic Software Analysis

Methodology

Experiments were conducted in two stages. In the initial trials, thixocast and rheocast samples were examined in the T5 and T6 conditions. Both conventional resistance furnace heating and fluidized bed heating was applied. The results from these experiments showed similarity in the heat treatment responses between T5 and T6 samples, but also raised questions about possible sources of error. External data was analyzed in a NADCA Transactions paper, which contradicted the first study and suggested that the high as-cast ductility was retained in the T5. These questions were resolved in the second set of trials, and the preliminary conclusions from the first set of trials were vindicated.

This work is still continuing, and work is in progress.

Salient Results

THT (rheocast) 1 inch samples

Ten bars were tested for each data point, but bars with macro-defects were excluded through fracture analysis using stereomicroscopy.

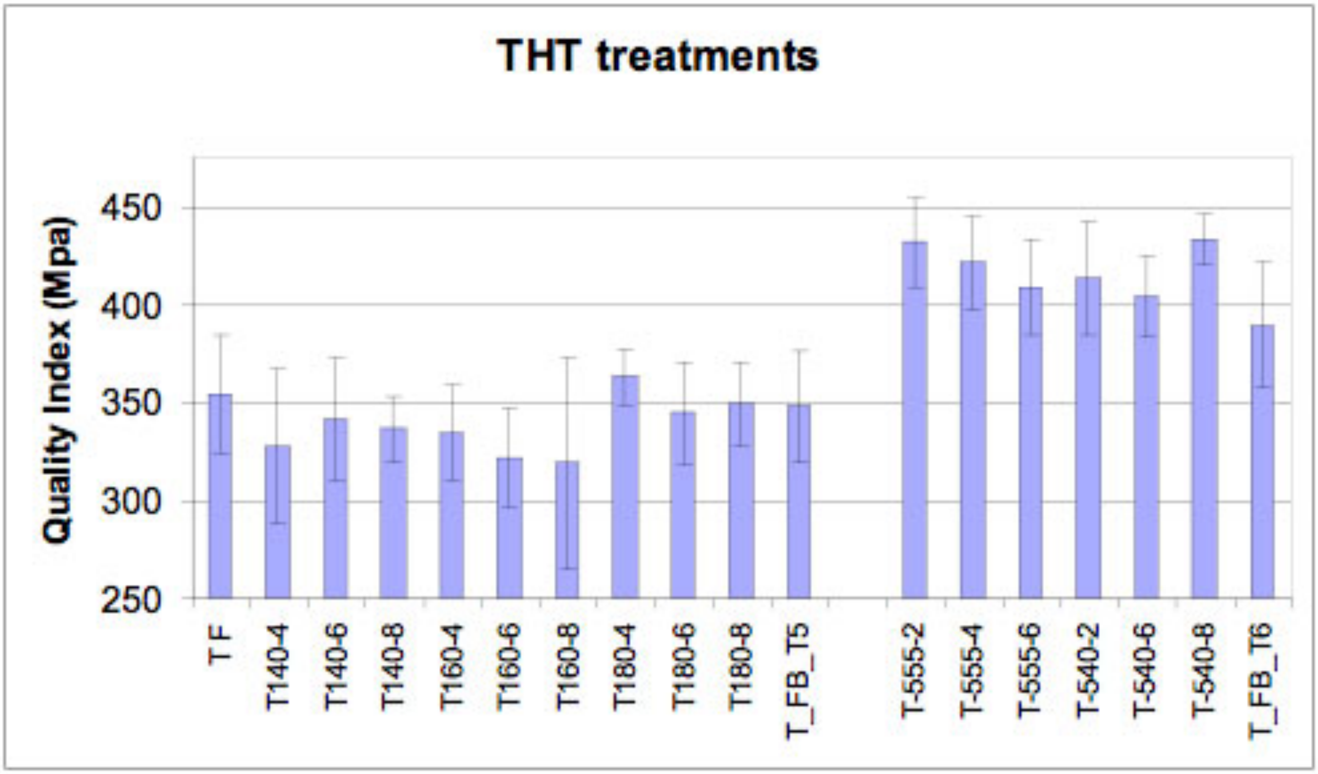

Figure 5.3.4: Quality Index values of 1" rheocast samples

The Quality Index results, shown in Figure 5.3.4, gauge the net effect on the alloy through heat treatments. When SSM material is successfully heat treated to retain the high as-cast ductility, Quality Index is not conserved, but instead increases above the as-cast value. Here, the T5 results only exceed the as-cast value at 180°C for four hours, but do so for both the SAG and THT 1" material. Quality Index results are closer to the as-cast value for the remaining T5 treatments than the thixocast T5 results. All T6 results show a net improvement of the Quality Index, as was expected. In T6 treatments using strontium as a eutectic modifier, the spherodization of silicon allows for an increase in both ductility and strength. Also of interest are the Quality Index results for the fluidized bed heat treatments that show comparable QIs to the conventional treatments, confirming that fluid bed T6's low elongation was exchanged for improved strength.

SAG (thixocast) samples

Ten bars were tested for each data point, but bars with macro-defects were excluded through fracture analysis using stereomicroscopy.

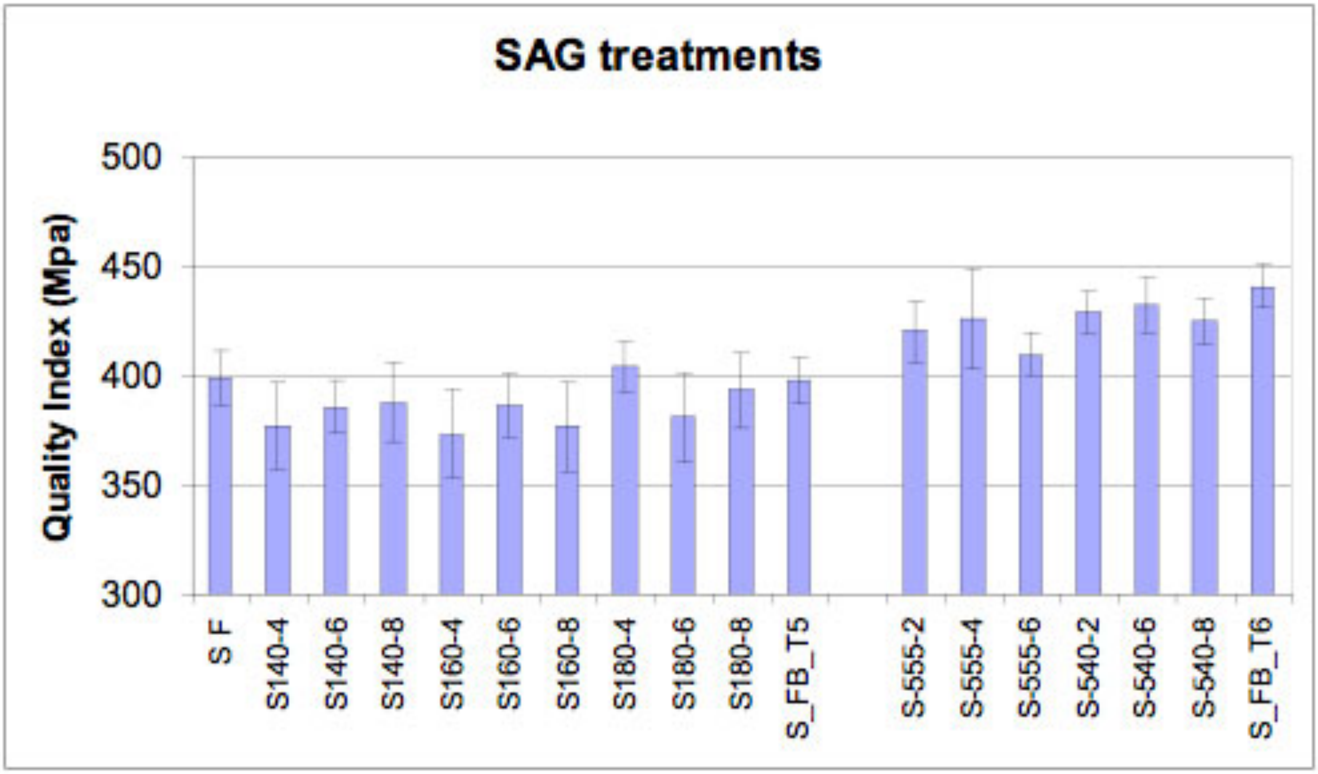

Figure 5.3.8: Quality Index values of thixocast samples

The Quality Index results in Figure 5.3.8 show the impact of heat treatments. When SSM material is successfully heat treated to retain the high as-cast ductility, Quality Index is not conserved but instead increases above the as-cast value. Here, the T5 results only exceed the as-cast value at 180 oC for four hours, but do so for both the SAG and THT 1" material. Quality Index results for the THT heat treatments are quite flat when compared to the rheocast results in the T5. All T6 results show a net improvement of the Quality Index, as is expected, but this improvement is not substantial. In T6 treatments using strontium as a eutectic modifier, the spherodization of silicon allows for an increase in both ductility and strength.

THT (rheocast) ¾" samples

Six bars were tested for each data point, but bars with macro-defects were excluded through fracture analysis using stereomicroscopy.

This set of samples was fabricated with a number of specific questions in mind. Following a general discussion of each graph is an analysis of these specific questions raised during earlier testing.

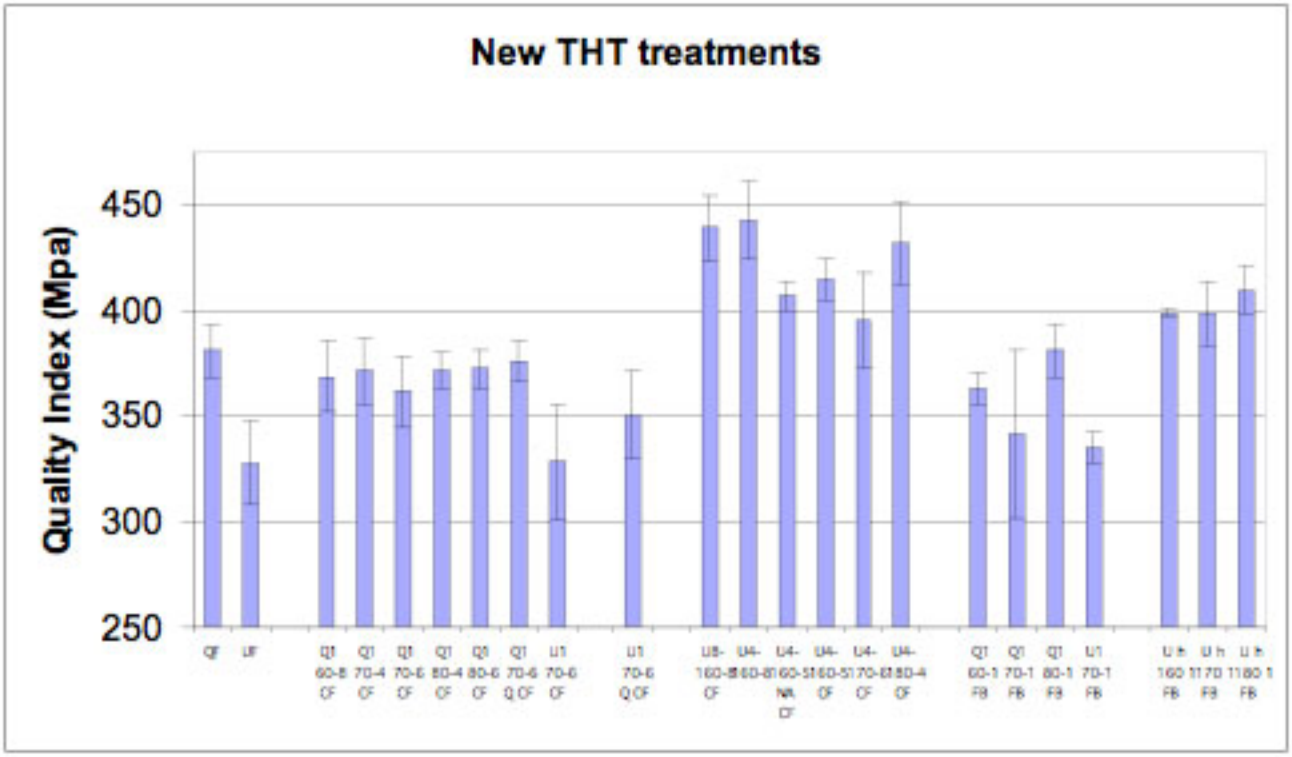

Figure 5.3.12: Quality Index values of 3/4" rheocast samples

In Figure 5.3.12, the first result which is apparent is the conservation of quality index in the T5. In both conventional furnace and fluidized bed treatment, the quality index values of the T5 bars do not exceed their F-temper counterparts within the limits of experimental error. The quality index of T6 bars, on the other hand, is not conserved (T6 QI values exceed F and T5 values for QI). Thanks to the spherodization of silicon, there is a net improvement in QI. It is also clear that the die quenched bars have superior properties as compared to the bars which were air cooled from the die.

Quenching bars between solutionizing and aging treatments shows a decreased quality index due to the effect this quenching has on elongation. Solutionizing for eight hours instead of four has no impact on Quality Index, but differences in UTS and ductility were apparent. As these above changes are relatively small, it can still be stated that eight hours of solutionizing is probably not necessary. Increasing natural aging from eight hours to 15 hours after the quench before artificial aging decreased the QI slightly, although aging temperature and time are a much larger factor.

T6 aging for eight hours at 160°C produces results very similar to aging at 180°C for four hours. T6 aging at 160°C for five hours results in a lower QI. Fluidized bed T5 results are comparable in QI to the non-fluidized bed T5 results. T6 fluid bed results are not as good as the most promising T6 CF results, suggesting an increased aging temperatures such as those used in the earlier trials would improve QI results. Alternately, an increased aging time could be employed at these lower temperatures.

Conclusions

- In the T5 condition in conventional furnaces, aging at an indicated furnace temperature of 180°C, corresponding to a part temperature of 170°C, consistently yielded the best results in the least time.
- Given the goals of fluid bed heat treatment, a minimal time in the furnace is key.

- It is the higher aging temperature treatments which produce the best results in a given time.
- The highest aging temperature used in these treatments was 204°C.
- T6 fluid bed trials using that temperature were also the most successful in that they resulted in the highest quality index in the least amount of time.
- Solutionizing above 540°C but below 560°C is recommended if this can be done without blistering or additional distortion in an industrial setting.
- A reduction in solutionizing times is possible in a furnace with uniform temperatures and precise controls.
- Significant differences in the heat treatment requirements of thixocast and rheocast components were not observed.
- Although many T5 components exhibited favorable combinations of strength and ductility, the Quality Index was conserved in these tests for T5 treatments.
- Although the unusual ductility retention has been observed in other systems, it was not observed in these tests.

Future Work

As is the case with many theses, there are many directions which could be pursued with this work as a starting point. Given the obvious advantages of fluid bed treatments, it would make sense to conduct additional dedicated research in fluid bed semi solid heat treatment. Key factors to investigate in the fluid bed are proposed sand-quenching technologies and a detailed analysis of the effects of fatigue and distortion under various fluid bed treatments on components of interest. In general, quench analysis may be a valuable tool in the study of the heat treatment behavior of this component.

There have been suggestions from industrial partners that the unusual T5 effect is in some way magnesium-linked. Detailed examination of properties with varied magnesium content (0.2-1.0% Mg) would be a way to investigate this phenomenon. There are a variety of different rheocasting methods, and it remains to be proven conclusively that all rheocast material heat treats exactly the same. Given variations in segregation during casting, aging and solutionizing times rather than temperatures would seem to be the key parameter.

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