

Modifying The Thermal Analysis Findings Of Cast Al-Si Alloys Due To The Presence Of Other Components

Sewara M. Shekhan
Northern Technical University, Iraq
sewara.m.shekhan@ntu.edu.iq

Abstract

Understanding how alloying elements affect the eutectic temperature and depression is crucial for determining the efficacy of a modification procedure using thermal analysis. The effects of magnesium, silicon, copper, and iron on sodium modification were examined in this paper. In addition, a critical review of the methodologies used by several commercial thermal analysis equipment to determine the temperature at which the unaltered melt reaches its eutectic point. Normal practice employs the use of literary equations for this purpose. The influence of alloying components on the eutectic point is taken into account in these equations. There is evidence that magnesium has an unexpected effect on depression indices. There was a significant decrease in the eutectic depression with increasing Si content and an increase with increasing Cu concentration, while the influence of iron was quite minor. Inconsistent cooling circumstances during the thermal analysis experiment may lead to systematic mistakes in thermal analysis systems that use literature-based equations to determine the eutectic reference temperature.

Keywords: Magnesium, Thermal Analysis, Cooling Circumstances.

1 INTRODUCTION

Al-Si alloys, because to their favorable metallurgical properties, are the most widely used casting alloys. Adding sodium or strontium during the modification process might further enhance mechanical properties; this were first reveled in the 1921 [1].

Without any adjustment, eutectic silicon crystallizes in lamellar morphology or an acicular, leading to subpar properties; however, when a modifying element is introduced, the silicon network undergoes a dramatic transformation, becoming extremely fine and fibrous, leading to a significant increase in elongation. The formation of silicon crystals is thought to be constrained by absorbed sodium or strontium atoms on the developing surfaces, according to recent studies of the process [2]. In turn, this causes the silicon crystals to undergo a process of forced twinning, which has two effects: first, it increases branching, and second, it significantly lowers the eutectic temperature. Therefore, thermal analysis utilized to regulate the degree of modification by measuring the so-called "depression," or the change in eutectic temperature between the start and end of a modification procedure. Other alloying elements, such as magnesium or copper, may be added to Al-Si alloys to further enhance their mechanical qualities. In addition to the hardening that occurs naturally, these ingredients also make it possible to subject the alloy to a heat treatment that includes solutioning, quenching, and aging. This allows for almost a threefold improvement in tensile strength and yield of an Al-7%Si-0.3%Mg alloy, for example, while maintaining an acceptable amount of elongation. Precipitation of metastable phases and submicroscopic containing Si and Mg during aging increases strength by acting as good impediments for the dislocation movement. Precipitated metastable Al-Cu phases are responsible for the hardening effect in the Al-Cu system, while both processes work simultaneously in AlSiCu alloys. More recent studies of magnesium's bond with strontium have shown that the Sr-modified The presence of magnesium evidently alters microstructure [3]. Image analysis revealed that when Mg content increased, the microstructural parameters, such as silicon particle size and aspect ratio, rose and became more inhomogeneous. The production of Mg₂SrAl₄Si₃ intermetallic phases is thought to be at the root of the modification's deterioration.

Manuscript received on: 13.11.2022

Accepted on: 30.11.2022

Published on: 04.12.2022

Issue DOI: doi.org/10.52688/15

However, specifically, it was shown that in unmodified Al-Si alloys, a magnesium content of 1.3 wt. % acts as a refiner for the eutectic silicon. Because the modification has such a profound influence on the microstructure and mechanical characteristics, a thorough quality assessment of the modification procedure must be done before casting. In most cases, a metallographic examination of a casting portion or other unique sample is the best option. This process is labor intensive and is usually carried out "off-line," or after the modified melt has been cast. As the microstructural impact is also dependent on the alloy and the cooling rate, if spectrum analysis is performed at all, all that can be learned is the relative abundance of the different types of modifiers. Therefore, thermal analysis is becoming more popular as a rapid procedure that may be employed before casting in many aluminum foundries. As indicated above, the impact of modification may be evaluated by comparing the lowered eutectic temperature to that of the unmodified alloy. Since this so-called "depression" corresponds according to the microstructural properties of the eutectic silicon as determined by image analysis, it may be used as an indicator of the quality of the alteration [4]. There are two major issues that come up when doing thermal analysis. Experimental aspects including cooling rate, alloying, crucible, trace, temperature and melt components may all impact the thermometric analysis findings. The accuracy of thermal analysis is proportional to how well the cooling conditions used represent the actual circumstances under which the casting was made. The precision with which changes to the cast component may be predicted [5]. Conducted extensive research on the impact of trace elements and alloying elements on magnesium alloys.

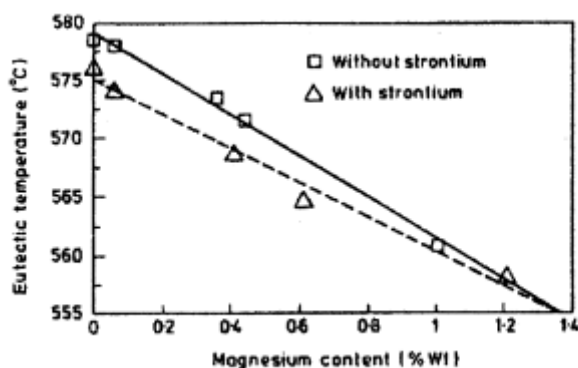


Figure 1: The eutectic temperature of unaltered and strontium-modified Al-Si alloys drops as a function of magnesium content.

As shown in Fig. 1, the depression values and eutectic microstructure of a modified Al-Si alloy decreased as magnesium content increased. However, there is another real-world challenge related to finding the eutectic reference temperature. For the depression to be computed, the cooling curve of the changed melt and the eutectic temperature of the unmodified melt are both required. This primarily requires a thermal study of the unmodified melt, which may be time-consuming and occasionally impossible if the metal is already strontium-modified before it is delivered. In this case, commercial thermal analysis systems are used. issue in two distinct ways. Most of these programs require as an input the reference temperature, which may be determined using empirical formulae found in the literature that account for the impact on eutectic temperature [5,8] due to the influence of alloying components. As input, the alloying element concentrations are used to partly apply these equations in the analytical software. being all that is needed to complete the calculation. Another theoretical option is to examine the modified melt's cooling curve in relation to ternary eutectics like AlSiMg or AlSiCuBy determining how much of an impact the ternary reaction has. It is possible using the locations of the peaks in the first derivative curve, a hypothetical reference temperature for the unaffected melt may be determined [8]. As a result, understanding the precise impact of alloying elements on the eutectic temperature is a prerequisite for using thermal analysis in the foundry. Understanding how these components affect eutectic depression is also crucial for evaluating modification quality. So far, this has not been precisely measured in terms of the important factors. The study presented here seeks to comprehensively explore the effect of the principal alloying elements, including Cu, Mg, Si. The microstructures were also examined by metallography to ensure that the thermal analysis findings were accurate.

2 METHODS USED IN EXPERIMENTS

The investigation was divided into two portions because sodium and strontium behave differently. Sr modification studies were conducted on an Al-11%Si base alloy. As part of these studies, the effect of experimental factors such as crucible temperature and melt on the outcome of a thermal analysis is discussed by W. Schneider and L. Heusler [3].

At first, we looked at the effect of magnesium by contrasting AlSi11 without any Sr additions to Al-Si11 with 0.45 wt.% Mg added. The Al-12%Si alloy was employed once again, this time with varying amounts of magnesium added (0, 0.2, 0.35, 0.45, 0.6, and 1.0 wt.%) for a more in-depth analysis. Experiments with variable Si concentration were conducted on binary Al-Si alloys containing 6, 5, 7, 12, 14, and 17 wt.% Si in relation to sodium modification. By using the same concentrations seen in strontium-modification research, the effect of magnesium was also investigated. Using an Al-9%Si alloy allowed for a more direct extrapolation of findings to widely used secondary alloys like A381 and A351. This allowed for a quantitative analysis of the effects of Cu and Fe. The effects of changing the Cu concentration to 1.21, 1.15, 1.12, 2.320, 2.178, and 3.5 wt.% and the Fe concentration to 0%, 0.35%, 0.50%, 0.75%, and 1.00% were studied. Primary aluminum (98.6 wt%), pure Si (98.7 wt%), pure Cu (97.77%) and pure Mg (98.888 wt%), were used to create all of the alloys described. An Al-9% Fe master alloy was used for the iron addition, while a master alloy rod containing 20% Sr was used for the Sulphur modification. Melted sodium was altered by adding pure sodium wrapped in aluminum foil. All of the molten materials were prepared in a 60-kilogram (kg) electric furnace fitted with a crucible made of silicon carbide. Silicon was melted at 800 °C and cooled to a pouring temperature of 731 °C, where it was alloyed with the other elements. Modifiers (if necessary) were added to the alloy after the composition was adjusted using spectral analysis, and the melt was then vigorously stirred. Three systems from various manufacturers were used to conduct thermal analysis on both the unmodified and modified melts. The system A group utilized a ceramic crucible. The crucibles of System B were made of steel and crooning sand. A crucible made of thin-walled steel was needed for system C. The cooling curve was also recorded using an external data acquisition device, and all systems were run in simultaneously. Smaller samples weighing about 101 g were cast in a steel mold and subjected to faster cooling rates. The data collecting system was used to remeasure the cooling curve. Each alloy composition had three samples cast in each system and their cooling curves recorded. For the purpose of correlating depression values with the resultant microstructure, metallographic analysis was performed on a subset of the samples.

3 DISCUSSION

3.1 Effects of Varying Experimental Conditions

Melting temperatures between 800 and 950 degrees Celsius and crucible temperatures between ambient and 350 degrees Celsius were tested, and the results revealed that none of these variables affected the resulting smelting and sintering temperatures (Fig. 2). While the effects of the crucible material are noticeable. Eutectic temperatures came close to the theoretical value of 577 C in the ceramic and steel crucible. The scoring sand lowered it by 1 K, and the steel mold lowered it by around 4 K below the soother crucibles' observed eutectic temperatures. It was observed that the eutectic reaction occurred at a larger undercooling, resulting to a lower proposed eutectic temperature, as a direct result of the increased cooling rate. As the Sr content of the experiment rises, the depression values show that the crucible material has no effect, with the exception of the steel mold. It seems that the expected increase in depression with Sr content is occurring, at least initially. This 101 ppm Sr maximum temperature drop of 4K result for the alloy Al-11%Si under consideration, was accomplished. Although the depression value was shown to drop somewhat with increasing Sr content, subsequent increases in Sr content did not have this effect (Fig. 3). If rapid cooling rates are typical, the eutectic depression brought on by the change will worsen. Extremely high depression values of 10 K were attainable while utilizing the steel mold after Sr alteration, which is remarkable. Microstructure was also partly altered in Sr-free samples cut from the steel mold, as seen by metallography (Figure 3). High cooling rates have the same impact on the eutectic microstructure as a modification treatment, which is consistent with the findings of earlier studies. Therefore, it is advisable to employ cooling rates that are close to those predicted in the actual casting if thermal analysis is to be performed to evaluate the modification impact on the microstructure.

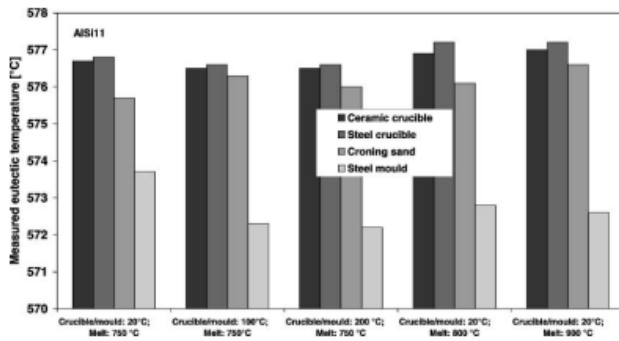


Figure 2: AlSi11 eutectic temperature vs crucible material, melting, and refractory temps.

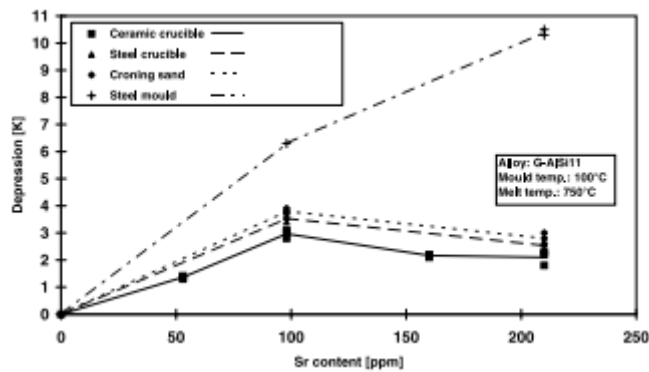


Figure 3: Eutectic slump of an AlSi11 metal as a result of the Sr's content and mound material.

3.2. The Magnesium Effect

3.2.1 Modification with strontium

Under the identical conditions, but this time with 0.35 wt.% Mg added, we reran the set of experiments with increasing Sr concentration described above. Magnesium's presence in the system caused a 4 K depression at 50 ppm Sr, as seen by the depression curves, and the depression peaked at 7-8 K at 101-151 ppm Sr (Figure 4). To increase the MDV from 4.2 to 8 K, 0.45 wt.% Mg was added. This fact has to be considered when determining an accurate thermal analysis of the change. An issue is that Compared to the Mg-containing specimen modified with a MDV of 8 K (Figure 5a), the Al-Si eutectic structure modification in the Mg-free specimen altered with 101 ppm Sr and a depression value of 4.2 K is superior (Figure 5b). Due to the magnesium's clear impact, researchers decided to go further by systematically changing the magnesium percentage of the alloy from 0 to 1 wt.%, using Al-11%Si as the starting material. Afforded no Sr supplementation

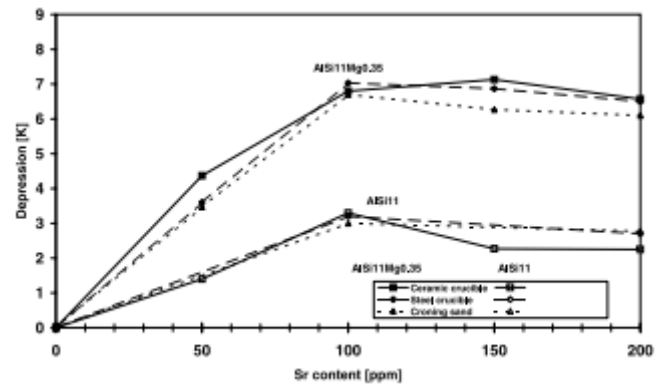


Figure 4: In AlSi11 and AlSi11Mg alloys, eutectic depression is shown to be proportional to the Sr concentration.

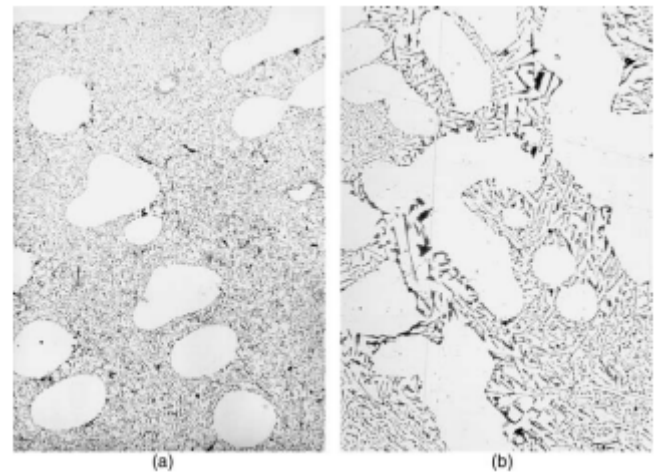


Figure 5: Samples of AlSi11 alloy were micro-structured for thermal analysis.

Melt temps between 700 and 950 degrees Celsius and furnace temperatures between ambient and 450 degrees Celsius were investigated, and the findings demonstrated that none of these factors impacted the final smelting and sintering temperatures (Figure 2). (Figure 2). However, the impact substance from the crucible stands out more clearly. In the crucible made of ceramic and steel, temperatures neared the theoretical value of 578 C, which is the eutectic point. As the sand scrounged, its temperature plummeted by 12 degrees Celsius. while the steel mold lowered it by roughly 4 K below the sother crucibles' recorded seutectic temperatures. It was discovered that the eutectic reaction happened at a bigger undercooling, leading to a lower predicted eutectic temperature, as a direct consequence of the higher cooling rate. As the Sr content of the experiment grows, the depression values demonstrate that the crucible material has little influence, with the exception of the steel mold. It appears that the projected rise in depression with Sr

content is happening, at least initially. This 100 ppm Sr maximum temperature reduction of 43 K

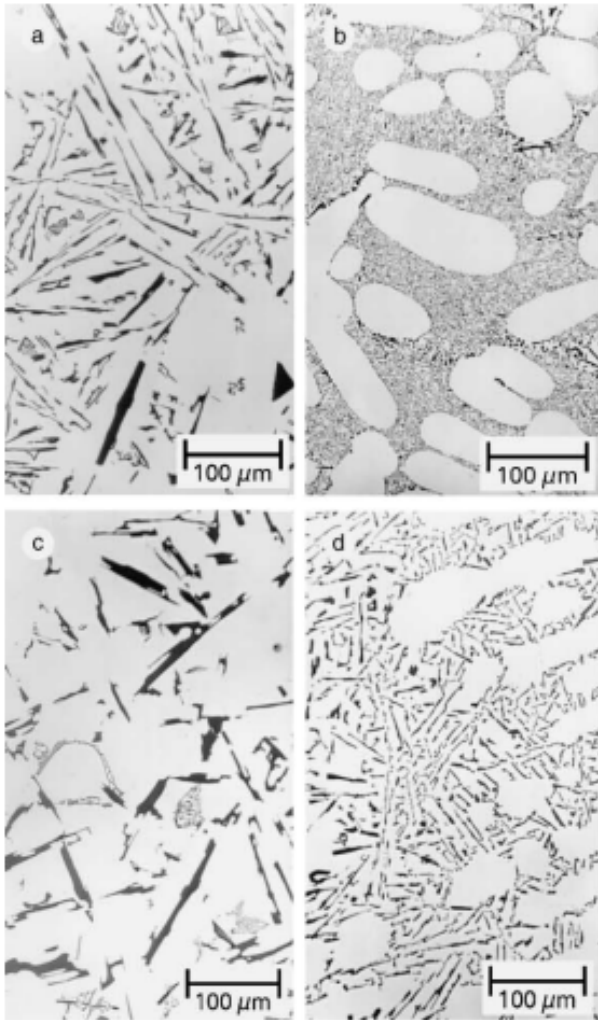


Figure 6: Microstructures of thermal analysis samples with varied Mg concentration (base alloy: AlSi11) compared before and after Sr modification. (a) 0.1 wt. % Mg and 0 ppm Sr, (b) 0.1 wt. % Mg and 200 ppm Sr (c) (0.45 wt. %) Mg, 0 ppm Sr; (d) (0.45 wt. %) Mg, 200 ppm Sr.

4 INCORPORATING SODIUM INTO THE FORMULA

The effect of magnesium on sodium is conceptually similar to that of strontium, but there are important distinctions (Figure 7). In the presence of low Na concentrations

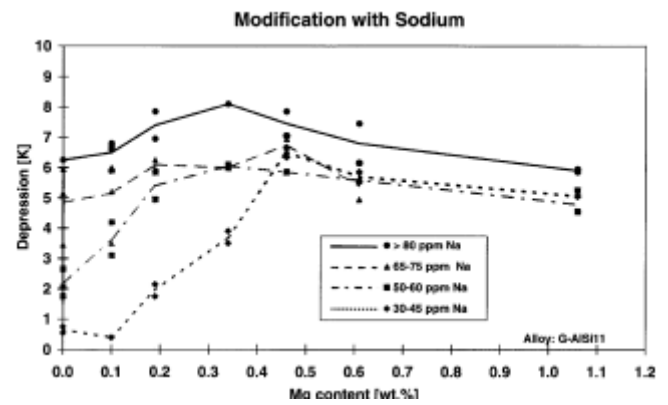


Figure 7: Dependence of eutectic depression on magnesium content (base alloy: AlSi11, Na modified).

The depression values rise from 0 K with no Mg to 7 K with 0.35 wt.% Mg, and then fall to 4 K with concentrations of 30-45 ppm, which often correlate to an undermodification. Increases in Na and Mg up to 0.35 wt.% raise the depression cutoff to greater amounts. Once the Mg content rises over 0.45 wt.%, the depression nearly never changes across Na concentrations. When testing various quantities of Mg, the highest concentration was obtained only when 80 ppm Na was present. These findings are consistent with the metallographic findings. Increasing the Na concentration to 70 ppm enhanced modification in alloys without magnesium. However, the eutectic microstructure remained almost constant across all Na concentrations, even if the modification was somewhat poorer at 0.45 wt.% Na content of 81 ppm resulted in a better altered structure, but with some adjustment areas, which linked with increased depression values. In contrast to Sr modification, there is minimal change in depression levels with increasing Mg concentration between the modified (64-74 ppm Na) and overmodified (>82 ppm Na) ranges. With 0.35 wt.% Mg added, depression increases from 7 to 9 K, and the eutectic modification degrades as a result. as was seen in the experiment with Sr amendment. Therefore, the Mg concentration must always be taken into consideration for the evaluation of Na modification.

4.1 Silicon's Impact

As was predicted, silicon has a modest effect on the eutectic temperature of binary Al-Si alloys. The eutectic temperature was found to be between 575 and 577 C for the studied range, which was from 5 to 18 wt.% Si. Taking the thermocouple's measurement error into account, this may be treated as a constant. When comparing these two materials,

the Na-adjusted Al-11%Si alloy has a significantly more obvious depressed silicon dependence (Figure8). Depressive symptoms are reduced from

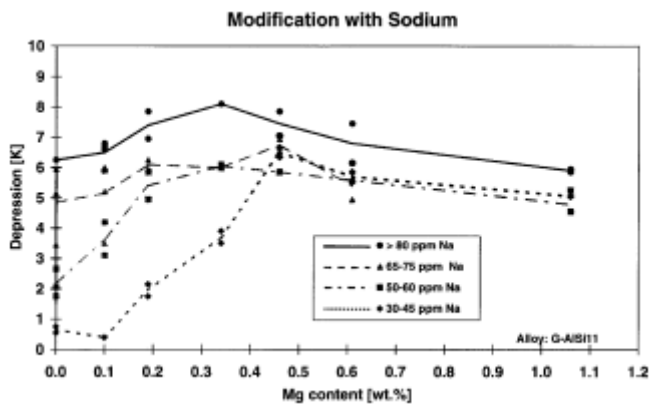


Figure 8: Dependence of eutectic depression on magnesium content

5 CONCLUSION

The study established that thermal analysis measurements of eutectic depression may be utilized to monitor and manage the efficacy of a therapy adjustment. Melt and crucible temperatures, together with other experimental factors, don't make much of a difference. However, alloying elements like as Mg, Cu, and Si have a considerably more noticeable impact and must be taken into account when thermal analysis is put into practice. When the Si content was increased, the depression values dropped but the microstructure remained mostly same. Higher depression values and a somewhat over adjust eutectic microstructure are seen with increasing Cu contents. When it comes to thermal analysis for the purpose of change control, magnesium displays the most essential behavior. This is due to the in correlation between the eutectic depression and the resulting microstructure, which is highly dependent on the Mg concentration. Only Cu and Fe were researched as part of a multiple-element effect, and it was discovered that these two elements may be treated independently of one another. Measuring the cooling curve of the unaltered melt is the best, if time-consuming, method for establishing the reference temperature. If the eutectic temperature equations are calculated under cooling circumstances the same as those found in a thermal analysis system, they may be utilized to determine the eutectic temperature given the alloy's constituent elements. It seems that using ternary effects to extrapolate alloying element concentrations from the cooling curve is inaccurate and should be avoided.

Defining bounds for the depression values is essential for evaluating a therapy for modification using thermal analysis. These restrictions should be based on the alloy being used and the cooling conditions in the critical areas of the cast object. So, they can't be defined until the target microstructure has been specified.

6 REFERENCES

- [1] A. Pacz, US-Patent, nr. 1,387.990, 12.08.1921.
- [2] S. Lu, A. Hellawell, Modification and refinement of cast Al-Si alloys, *Light Metals* (1995) S.989-S.993.
- [3] A. Joenoes, E. Gruzleski, Magnesium effects on the microstructure of unmodified and modified Al-Si alloys, *Cast Metals* 4 (2) (1991) S62-S71.
- [4] L. Heusler, W. Schneider, Recent investigations of influence of P on Na and Sr modification of Al-Si alloys, *AFS Transactions* (1997) S915-S921.
- [5] X.-G. Chen, Dissertation: Kristallisation des AlSi-Eutektikums und Anwendung der thermischen, Analyse zur Kontrolle der Veredelung, RWTH Aachen, 1991.
- [6] G. Stuhldreier, K.W. Stoffregen, Erfahrungen mit der thermischen analyse von G-ALSi-Legierungen, *Giesserei* 68 (13) (1981) S.404- S.409.
- [7] D. Apelian, G.K. Sigworth, K.R. Whaler, Assessment of grain refinement and modification of Al-Si foundry alloys by thermal analysis, *AFS Transactions* (1984) S.297-S.307.
- [8] D. Dunkelmann, Thermoanalyse von Aluminium-Schmelzen mit € systematischer dokumentation, *Giesserei* 82 (18) (1995) S.678- S.681