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Influence of Different Si Levels on Mechanical Properties of Aluminium Casting Alloys

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Abstract

AlSi7 and AlSi11 are the most commonly used materials in aluminum alloy wheel production. The main difference is the heat treatment application; for wheel production AlSi7 is usually used in heat treated form while AlSi11 is not. Heat treatment processes play a vital role on production costs. More than fifty percent of aluminum wheels are heat treated however the exact value varies between different manufacturers. Additional heat treatment costs directly affect the competitiveness of the manufacturer. In this study the material properties of an alternative Si level between AlSi7 and AlSi11 are examined and the effects of these intermediate Si levels on mechanical properties are compared with that of AlSi7 and AlSi11. The aim of this study to examine the possibility of obtaining mechanical properties of heat treated AlSi7 with a non-heat-treated material differing only in Si content. In this experiment all processes and casting parameters for different material types are the same except for the Si content. In addition to an experimental study, the mechanical properties of the alternative material are simulated by utilizing a material analysis software and these properties are compared with experimental results. Thus, correlation between simulation and experimental study results can also be examined. As a conclusion, the alternative non-heat-treated material is presented to manufacturers. These results may be used to bypass the heat treatment process and to decrease the cost of final product.

Key words

Aluminum, Heat Treatment, Mechanical Properties,
Simulation of Material Properties

1. INTRODUCTION

In the last decades, the importance of weight reduction is growing dramatically in the automotive industry. Not only fuel efficiency, but also emission values which is regulated by rule-maker lead the automotive manufacturer to use lightweight materials. Considering the low density, better mechanical properties, easier machinability, corrosion resistance and recyclability, Al-Si based alloys are widely used in automotive components. Especially, AlSi7 and AlSi11 dominate the Al-Si based alloys as a main material in wheel production. The main difference is the heat treatment application; for wheel production AlSi7 is usually used in heat treated form while AlSi11 is not. The primary reason of heat treatment is improving the mechanical properties. Many authors investigate the optimization of heat treatment to get better mechanical properties [1],[2],[3]. Main purpose of these optimization studies is cost reduction because the heat treatment processes play a vital role on production costs. The exact value varies between different wheel manufacturers, but more than fifty percent of products are heat treated and heat treatment costs directly affect the competitiveness of the wheel manufacturer. In this study the properties of an alternative Si level between AlSi7 and AlSi11 is examined and the effects of these intermediate Si levels on mechanical properties are compared with that of AlSi7 and AlSi11. The aim of this study to examine the possibility of obtaining mechanical properties of heat treated AlSi7 with a non-heat-treated material differing only in Si content.

2. MATERIALS AND METHODS

In addition to two main materials, the alternative Si level material was produced by mixing 50% percentage of each two main material ingots. Thus, AlSi9Mg which is known as hypoeutectic silumin is obtained as an alternative alloy. The alternative alloy was melted in a SiC crucible furnace and all serial production procedures such as grain refinement, modification and degassing were applied in accordance with related regulations. Grain refinement was provided by Al-5Ti-1B rods, alloys were modified by Strontium (AlSr15) and degassed by nitrogen. Quantity of Al-5Ti-1B rods and Strontium (AlSr15) were calculated and added according to chemical content which was measured by OES (Optical Emission Spectrometry) (As shown in Table 1.). [5],[6],[7]

Table 1. Chemical composition [7]

	Si	Fe	Cu	Mn	Mg	Zn	Ti
AlSi7	6,5-7,5	0,15	0,02	0,10	0,30-0,45	0,07	0,10-0,18
AlSi9	9,0-10,0	0,15	0,02	0,05	0,30-0,45	0,07	0,15
AlSi11	10,0-11,8	0,15	0,02	0,05	0,1-0,45	0,07	0,15

The first step of casting process is mold preparation. In mold preparation step, wheel mold was coated and preheated to minimize the casting defects such as shrinkage, cracks and metal flow problems. Directional solidification leads to an increase in mechanical properties and a decrease of casting defects. The directional solidification can be controlled by utilizing the cooling channels in the mold. All casting process parameters such as pouring temperature, mold coating type, preheating mold temperature and cooling channels properties were the same as in serial production.

The second step of casting process is the die casting. 36 Wheel specimens were casted by LPDC (Low Pressure Die Casting) method at 720 ± 20 °C for each 3 samples sets (AlSi7 – AlSi9 – AlSi11) to investigate differences in metallurgical and mechanical tests.

Table 2. Specimen configuration

	Metallurgical Tests				Mechanical Tests	
	As Cast	**With HT* Without Wheel Base Coating**	**Without HT* With Wheel Base Coating**	**With HT* With Wheel Base Coating**	**Without HT* With Wheel Base Coating**	**With HT* With Wheel Base Coating**
AlSi7	1	1	1	1	16	16
AlSi9	1	1	1	1	16	16
AlSi11	1	1	1	1	16	16

**HT: Heat Treatment*

Production process was finished with heat treatment application. Heat treatment starts with solution treatment and continues with water quenching and is finalized with artificial aging. The next step of production process is machining. Machining parameters depend on the technical drawing, tolerances, wheel types and milling tools.

To minimize these complexity, all wheel specimens were casted into same mold and machined with same machining program and parameters. Machined wheels were deburred and inspected, all specimens were also controlled by a helium-based leakage detector to detect cracks in rim section.

The final step of wheel production process is painting. This process contains three phases; first phase is primary coating; second phase is the color coating and third phase is clear coating. All coatings are applied in an oven since a certain curing temperature is required. Curing temperature is between 100 °C - 210 °C. In a sense, the wheel base coating can be called as secondary artificial ageing. In this study, two different sets, one with wheel base coating and one without wheel base coating were investigated with regarding to metallurgical properties to understand the effect base coating.

In addition to tensile test specimens obtained by machining of wheels, some tensile test specimens were produced by gravity casting method. Figure (1.a) shows LPDC (Low Pressure Die Casting) method and Figure (1.b) shows permanent mold for gravity casting tensile test specimens.

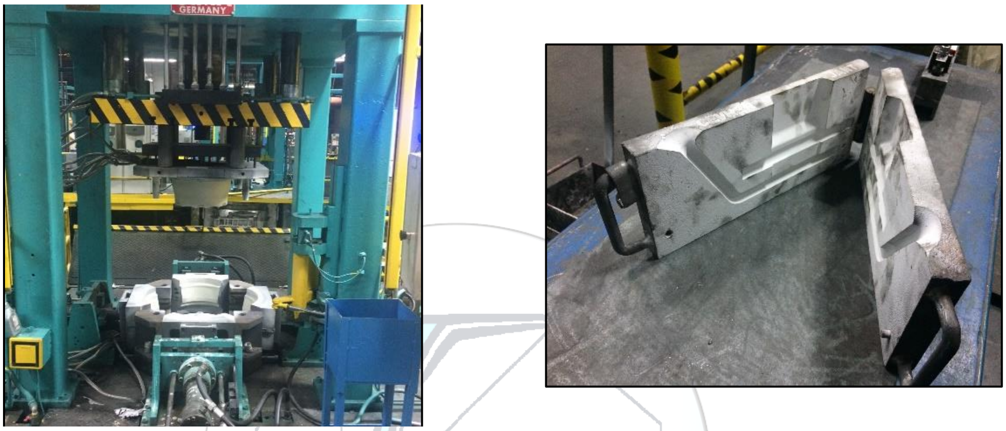

Figure 1. (a) LPDC (Low Pressure Die Casting) method (b) Permanent mold for tensile specimen

All microstructure samples were prepared in accordance with standard metallographic techniques. First, samples were grinded with SiC paper and polished. Second, samples were etched with 0.5% HF solution and examined with an optical microscope. Thermal analysis was conducted by an IDECO thermal analyser that can measure with ±0,1 °C accuracy and can report the grain size. Both types of tensile test specimens were machined and finalized according to DIN 50125 [9] and tested according to EN ISO 6892-1:2016 [10] with a Zwick Z100 model test machine.

Impact tests are applied to verify the wheel shock loading resistance. The impact test can simulate a curb stone or pothole hit and the impact load is dependent on axle load of the car.

Damage on wheels is evaluated in accordance with related specifications and standards. [11],[12]The wheel is considered to fail when the following are observed: visible fractures / cracks, separation of the centre from the rim and air pressure loss in 1 min. [12]

Finally, all metallurgical and mechanical tests are completed in laboratory environment at room temperature.

3. RESULTS AND DISCUSSION

Specimens were investigated with regards to metallurgical and mechanical properties. First, microstructure and macrostructure were obtained. Differences between the samples were examined. Second, UTS (Ultimate Tensile Strength), YS (Yield Strength) and Elongation (ε%) and hardness values were measured. Finally, impact tests were applied to final product. All these steps play a vital role in validation of a wheel.

Chemical contents of the samples are shown in Table 3.

Table 3. Chemical composition of samples

	Si	Fe	Cu	Mn	Mg	Zn	Ti
Sample Group #1	10,765	0,1113	0,0013	0,0029	0,173	0,0031	0,1206
Sample Group #2	9,000	0,1076	0,0012	0,0027	0,304	0,0039	0,1166
Sample Group #3	7,151	0,1070	0,0011	0,0025	0,302	0,0033	0,1203

3.1. Microstructure Analysis

The microstructures of the alloys with different Si level are shown below. All microstructures in Figure 2 are as cast and before heat treatment. Figure 2 (a) shows the sample with highest Si level and higher amount of Al-Si eutectic structures may be observed. Figure 2 (b) shows intermetallic phases and structure. Figure 2 (c) shows lowest Si level and a higher amount of α-Al dendrite may remarked.

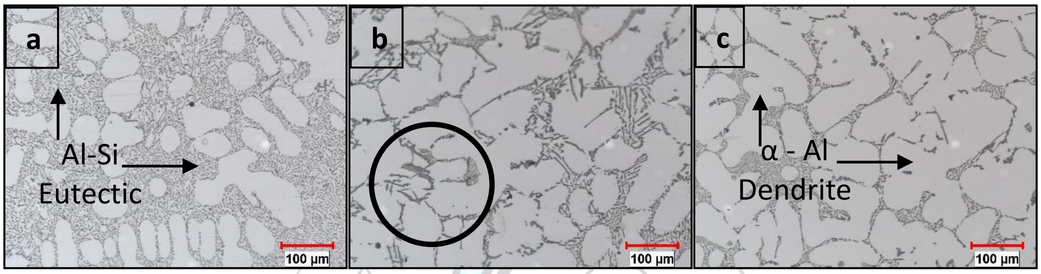

Figure 2. Microstructure of (a) Sample Group #1 as cast (b) Sample Group #2 as cast (c) Sample Group #3 as cast

All microstructures in Figure 3 are obtained from the final product, i.e. after heat treatment and base coating. Figure 3 (a) shows globular structures which are more invisible after heat treatment. Figure 3 (b) shows a decrease in intermetallic phases. Figure 3 (c) shows that Si particles are distributed in the Al matrix uniformly.

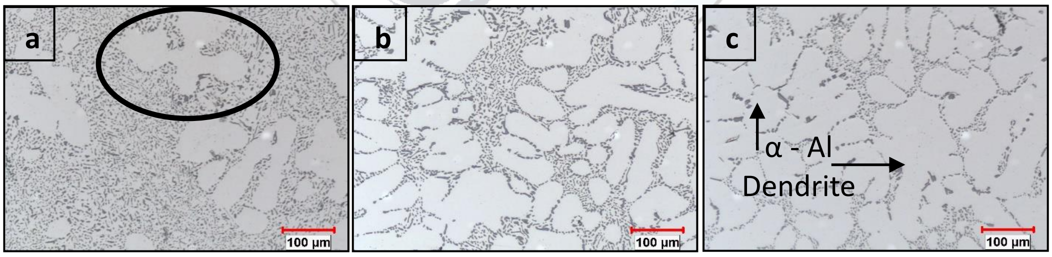

Figure 3. Microstructure of (a) Sample Group #1 as final product (b) Sample Group #2 as final product (c) Sample Group #3 as final product

3.2. Tensile Test Results

Tensile specimens are obtained by two different approaches. Firstly, by gravity casting into a permanent mold and secondly by obtaining from wheel spoke directly with machining. Elongation values of sample group #2 are at the lowest level. On the other hand, UTS and YS are better as sample group #3. As expected, heat treatment plays an important role.

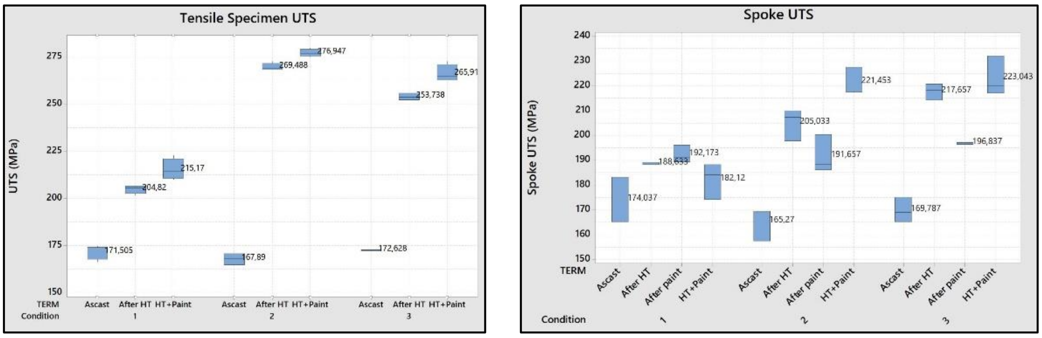

Figure 4. (a) UTS of Tensile Test Specimen (Permanent Mold) *(b) UTS of Wheel Spoke*

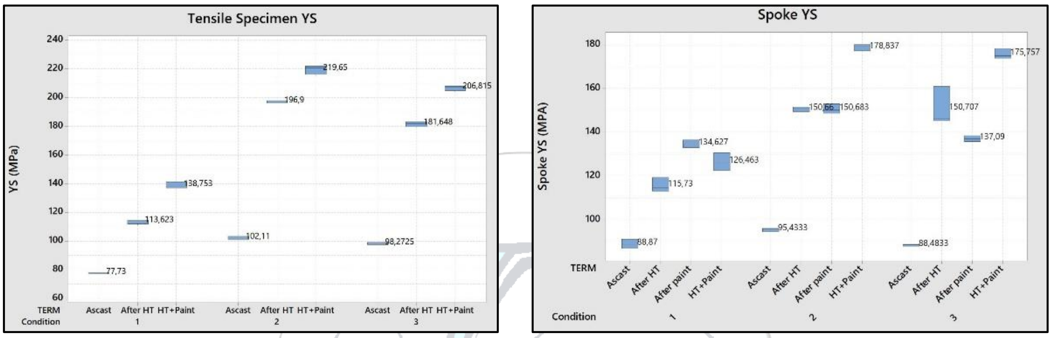

Figure 5. (a) YS of Tensile Test Specimen (Permanent Mold) *(b) YS of Wheel Spoke*

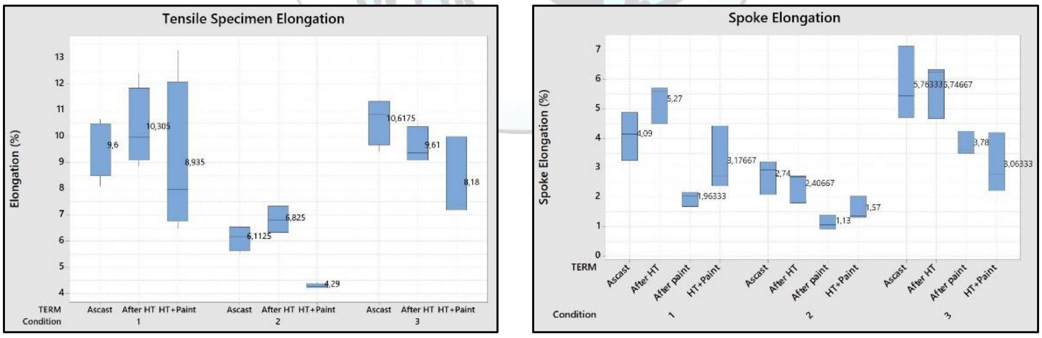

Figure 6. (a) Elongation of Tensile Test Specimen (Permanent Mold) *(b) Elongation of Wheel Spoke*

3.3. Hardness Results

Hardness Brinell values were measured for (Sample group #1, Sample group #2, Sample group #3) at 3 stages: After heat treatment, after base coating and after heat treatment + base coating.

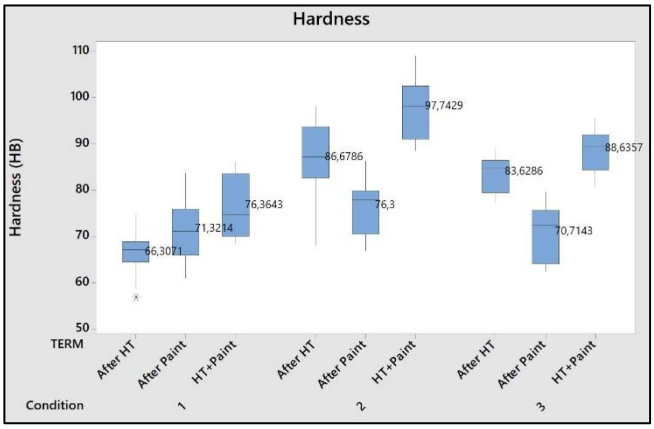

Figure 7. Hardness values

As seen figure above, sample group #2 (AlSi9 set) shows a higher average hardness at all 3 stages. The hardness may affect the impact values negatively.

3.4. Charpy Impact Test Results

Six test specimens which are prepared according to 'ISO 148-1: Metallic materials – Charpy pendulum – Impact Test' have been used to evaluate the toughness. [14] The results for all specimens are tabled below:

Table 4. Charpy Impact Test Results

	Sample Group #1		Sample Group #2		Sample Group #3	
	Heat Treated	**Non – Heat Treated**	**Heat Treated**	**Non – Heat Treated**	**Heat Treated**	**Non – Heat Treated**
			J (Joule)			
Specimen #1	4	4	2	2	3	3
Specimen #2	4	4	2	2	3	2,5
Specimen #3	4,5	3	3	2	4	3
Specimen #4	4	3	2	2	3	2
Specimen #5	4	3	2,5	2	3	3
Specimen #6	4	3	2	2	4	3
Average	4,08	3,33	2,25	2,00	3,33	2,75

According to results, the worst Charpy impact values are obtained from sample group #2. In addition to this, heat treatment helps to improve the impact values. Standard deviation is max. 0,5 for all measurements.

3.5. 13° Impact Test Results

Conducted according to 'Light alloy wheels – Impact test / ISO – 7141' Standard.

Table 5. 13° Impact Test Results

		OK	NOK
Sample Group #1	Heat Treated	650 Kg.	675 Kg.
	Non – Heat Treated	600 Kg.	625 Kg.
Sample Group #2	Heat Treated	-	450 Kg.
	Non – Heat Treated	-	450 Kg.
Sample Group #3	Heat Treated	575 Kg.	600 Kg.
	Non – Heat Treated	500 Kg.	525 Kg.

The weight is calculated according to wheel model. In this study, the weight is 450 Kg. and stopped with failure. The load is increased with extra 25 kg and the load reach final value which cause failure. As a result, sample group #2 failed with 13° impact tests, on the other hand, sample group #1 and #3 show better result from %11 to %44 according to calculated wheel load. Clearly, heat treated samples give better impact values, these results are actually in agreement with Charpy impact tests.

4. CONCLUSION

The chemical contents of all samples are in good agreement with literature. Microstructures and macrostructures were evaluated according to related specifications and results are approved. Al-Si eutectic, α-Al dendrite, modified Si structures may be observed.

'Permanent Tensile Specimen Mold' specimens of sample group #2 display almost same UTS and YS values with sample group #3 and better values than sample group #1. But, elongation (%ε) is lower than others. Chemical content differences –especially higher Mg- may lead these low elongation values.

Similarly, sample group #2 obtained by machining of 'wheel spoke' have similar UTS and YS values to sample group #3 and are better than sample group #1. Elongation (%ε) is lower than sample group #1 and #3.

The results of specimen obtained by machining 'wheel outer flange' displays the same trend with previous specimens; better UTS and YS, lower elongation (%ε).

The highest hardness (Brinell) results are obtained from sample group #2.

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