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Aluminum Alloy Development for Wheel Production by Low Pressure Die Casting with New Generation Computational Materials Engineering Approaches

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Abstract

Computational Materials Engineering (CME) is a high technological approach used to design and develop new materials including the physical, thermal and mechanical properties by combining materials models at multiple techniques. With the recent advances in technology, the importance of microstructural design in CME environments and the contribution that such an approach can make in the estimation of material properties in simulations are frequently discussed in scientific, academic, and industrial platforms. Determination of the raw material characteristics that can be modeled in a virtual environment at an atomic scale by means of simulation programs plays a big role in combining experimental and virtual worlds and creating digital twins of the production chain and the products. In this study, a new generation, alternative and effective approach that could be used to the development of Al-Si based wheel casting alloys is proposed. This approach is based on the procedure of optimizing the physical and thermodynamic alloy properties developed in a computer environment with the CME technique before the casting phase. This article demonstrates the applicability of this approach in alloy development studies to produce Al-Si alloy wheels using the low pressure die casting (LPDC) method. With this study, an alternative and economical way is presented to the alloy development studies by trial and error in the aluminum casting industry. In other respects, since the study is directly related to the automotive industry, the reduction in fuel consumption in vehicles is an expected effect, as the new alloy aims to reduce the weight of the wheels. In addition to conserving energy, reducing carbon emissions also highlights the environmental aspects of this study.

Keywords: Aluminum alloys, Application of information technology to the foundry industry, Low pressure die casting, Computational materials engineering, Microstructural and mechanical properties

1. Introduction

Aluminum (Al) is the second most-produced metal in the world after steel. With its wide range of physical and mechanical properties, it is preferred in many industrial areas, especially in the automotive sector. Aluminum properties such as lightness, recyclability, strength, corrosion and wear resistance, processing, and machining capacity make these alloys economically attractive for the production of wheels, which are safety parts in automobiles [1-5]. By alloying with other elements such as Si, Mg, Cu, the mechanical properties of pure aluminum can be significantly improved [6-8].

In the automotive industry, aluminum casting alloys with two different hypo-eutectic compositions, AlSi7 and AlSi11, are used in the production of wheels with low pressure die casting (LPDC). With the T6 heat treatment of AlSi7 alloy, its mechanical properties reach the values desired by the automotive main industry. On the other hand, the solidification range of AlSi11 alloy is very narrow since it is very close to the eutectic composition, this alloy supplies the mechanical values without heat treatment [6,9,10]. However, the subjects such as the development of new generation, light, and high-strength alloys as an alternative to these limited alloy compositions and the improvement of casting capabilities need to be studied in detail in industrial and academically.

In terms of metallurgy and materials science, it is well known that there is a strong link between chemical composition and microstructural properties [11]. However, this relationship cannot be easily resolved in complex and interrelated alloy systems. Today, it is possible to analyze the temperature-dependent thermophysical, microstructural, and metallurgical properties of alloy systems by CME software such as JMatPro and ThermoCalc. It is extremely important for aluminum foundries to have virtual alloy data on how the chemical composition can be used in research and development studies [12-15].

Since CME is a developing and prominent subject in recent years, academic applications on aluminum alloys in the literature are very limited. In the study by Jha and Dulikravich, solidification and heat treatment simulations were carried out to examine the precipitation kinetics of Al_3Sc crystals in 2xxx, 6xxx, and 7xxx series of aluminum alloys within the framework of the CALPHAD approach. The phase stability of Sc and Zr added alloys was analyzed with ThermoCalc. After solidification simulations, it was observed that the calculated liquidus temperature of the alloys increases with increasing Sc content. The authors stated that the mean radius of Al_3Sc grains increased with increasing temperature for both 2xxx and 6xxx alloys [16]. In another study, Assadiki et al. investigated the effects of alloying elements on the temperature stability of metastable phases such as α-Al_2Cu and β-Mg2Si using ThermoCalc equipped with TCAL4.0 database. During the thermodynamic calculations, it was observed that Li, Hf, Co, and Ce do not have a stabilizing effect on α-Al_2Cu and β-Mg_2Si phases. In addition, it was determined that the additions of V, Ti, Cr, Zr, and Sc increased the solidus temperature of α-Al_2Cu and β-Mg_2Si phases [17]. Jiao et al. investigated the effects of Fe-rich phases on both microstructural properties and fracture behavior in hypo-eutectic Al-Si alloy produced by the high-pressure die casting method. The Fe-rich phases in the Al-Si alloy were characterized by using X-ray tomography and JMatPro simulation. In this study, it was shown that there are three different phase morphologies of Fe-rich phases such as polyhedral, fine compact, and Chinese script-type shape for the AlSi10MnMg alloy [18]. When the studies carried out within the framework of CME approaches are examined, it has been observed that the research is mostly confirmed in a virtual environment. Although there is no verification phase of virtual data with pilot productions in general, this situation shows the gap in the literature on the subject.

In this study, the solidification characteristics, temperature-dependent physical and mechanical properties of Al-Si cast alloys with different Si amounts were determined with CME software. The data of the Al alloys developed in a virtual environment and pilot production are given by comparing them with the experimentally measured and/or calculated real values. AlSi7Mg0.3 casting alloy was selected as the basis and it was aimed to develop a new generation hypo-eutectic alloy composition with different silicon (Si) content, which could be an alternative to this alloy composition in terms of mechanical (tensile and yield strengths, elongation, hardness) and metallurgical (dendrite arm spacing, density, phase ratios, critical transformation temperatures) characteristics by using CME.

2. Experimental Procedure

2.1. Development of virtual new alloy compositions with CME

The compositional designs, based on a selection of main alloying elements' quantities and metallurgical parameters for alloy design and reveal of the effects on the basis of physical metallurgy, were calculated by using the CME software, which is equivalent to the AlSi7 casting alloy. For this purpose, JMatPro and ThermoCalc special material analysis software was used to calculate thermo-physical, metallurgical and mechanical properties of the traditional (AlSi7) and new alloy (AlSi5 and AlSi9) grades. With this software, many alloy properties such as stable and semi-stable phase equilibriums, phase transformations, true stress-strain graphs, solidification behaviors, and cooling curves were obtained. In this way, the virtual information repositories were created about the hypo-eutectic casting alloys with different Si content. The targeted compositions of hypo-eutectic aluminum casting alloys with three different Si contents used in CME studies before the casting process were given in Table 1.

2.2. Preparation of alloys and pilot production studies on an industrial scale

The alloy preparation processes required for industrial casting were carried out by determining the quantity of major alloying elements, master alloys, and additives. In industrial-scale wheel production, the alloys were prepared in accordance with the compositions developed virtually. The pilot production studies on an industrial scale were carried out in Cevher Alloy Wheels Company in the city of Izmir, TURKEY. Each alloy was prepared in an electric melting furnace with a capacity of 750 kg. In the preparation of alloys, the desired compositions have been achieved by adding pure Al and master alloys to the compositions of the ingots of AlSi7 and AlSi11 alloys, which are currently used in the production of wheels commercially. Grain refinement and modification processes were applied to the alloys with AlTi5B1 and AlSr10 master alloys during melting. After that, the melts were subjected to the rotary degassing process for the removal of dissolved hydrogen from the molten aluminum for 15 minutes. Then, the casting processes of the melts taken into the holding furnace of the LPDC unit were carried out, respectively. In order to keep the alloy compositions under control, samples were taken from the melting and holding furnaces during the production, and analyzes were carried out with an optical spectrometer regularly. In addition, melting and casting temperatures were continuously measured and recorded by using industrial-scale thermocouples. After the completion of an average of 5.45 minutes of casting cycle time, all the wheels removed from the die were X-Ray checked.

The same LPDC unit was used in all alloy castings. In addition, studies have been carried out on the same wheel model in castings, and the process parameters such as cooling rate, pressure, etc. are fixed for all productions. The casting temperature is set as 745°C for all alloys. 30 wheels for AlSi5, AlSi7, and AlSi9 alloy compositions were obtained by LPDC. For mechanical tests, at least 5 samples were taken from the regions of each wheel determined in the DIN EN ISO 6892-1 standard. In addition, the samples taken from the relevant regions were machined in accordance with the DIN 50125 standard for tensile tests. For the microstructure evaluations, samples were collected from the 15th wheel cross-section in each casting, including the hub, spoke and flange regions.

The LPDC dies used in the study for aluminum alloy wheels have many specially placed nozzles used for air cooling. The cooling circuit in the mold is a network of pipelines supplying 8 bars of air. Also, a mold has many cooling circuits. Compressed air is blown by the air nozzle connected to the circuit. While the temperature of the air is approximately 25 °C, this value can be reached to 500 °C in hole surfaces during the filling of the casting unit. The injected air first hits the bottom of the cooling nozzles, then the sidewalls, and passes into the atmosphere from the open side of the nozzle, thereby cooling the die [19]. A standard H13 hot work steel, which is a common die material, was used in the LPDC process in this study. Also, poteyaj protective coating process was applied to the steel die used in order to prevent the casting piece from sticking to the die.

2.3. Microstructural and mechanical analysis and evaluation

The characterization tests required before and after casting were carried out in accordance with the standards required by the automotive industry. In this context, microstructural analysis was performed as specified in the ISO/IEC 17025 standard. Inspections were carried out on the hub, spoke and flange, which are the metallurgical analysis areas determined on the wheel. The samples were prepared by classical metallographic sample preparation methods and exposed to Keller etching solution for 15 seconds. The eutectic structure, dendrite morphology, casting properties, and phase analyzes of the alloys were evaluated on the micrographs. In addition to optical microscope studies, the distribution of Al, Si, and Mg elements in alloys was obtained by mapping technique in studies performed with the scanning electron microscope (SEM) EDS module. Also, Brinell hardness measurements of wheels produced by the casting method were carried out along the wheel section from the hub to the flange according to ASTM E10 and ISO 6506 standards. Besides, the tensile tests were applied to the samples obtained from the products according to ASTM E8 and ISO 6892-1 standard. At the end of these activities, the virtual data and actual results from testing and characterization studies have been analyzed in detail on a wheel product basis, with comparison.

3. Results and Discussion

3.1. Results of CME studies

CME approaches were used to predict the final product properties physically, chemically, microstructurally, and mechanically of the alloys produced or desired to be produced before manufacturing. CME studies were carried out on hypo-eutectic Al alloys, using ThermoCalc and JMatPro, based on the amounts of Si that constitute the main alloying element of aluminum casting alloys. The determined alloy compositions were shown in Table 1.

Table 1.
Virtual alloy compositions used in CME applications and real alloy compositions obtained in pilot-scale productions (wt.%)

		Alloying elements (wt.%)									
Alloy		Si	Mg	Fe	Mn	Zn	It	Ni	Sn	Sr	B
Virtual values	AlSi5	5.0	0.3	0.1	0.0025	0.003	0.12	0.005	0.002	0.015	0.001
	AlSi7	7.0	0.3	0.1	0.0025	0.003	0.12	0.005	0.002	0.015	0.001
	AlSi9	9.0	0.3	0.1	0.0025	0.003	0.12	0.005	0.002	0.015	0.001
Optical spectrometer values	AlSi5	5.007	0.293	0.102	0.0022	0.0035	0.1084	0.0053	0.0026	0.0121	0.0013
	AlSi7	7.374	0.305	0.100	0.0026	0.0037	0.1214	0.0054	0.0027	0.0147	0.0004
	AlSi9	9.016	0.299	0.113	0.0026	0.0034	0.1239	0.0052	0.0020	0.0160	0.0008

In this table, the virtual data entered in CME studies and the actual data measured by optical spectrometry from the samples obtained after the melting process are included in this table. The AlSi7 alloy, which is currently used in the production of wheels by LPDC and is named A356 in industrial applications. This study focused on 3 alloy compositions with different Si amounts that can be alternatives to A356 alloy in terms of microstructural and mechanical properties and can be used in wheel production.

By means of ThermoCalc software calculations, it is possible to obtain the change of phase amounts in the microstructure of alloys depending on temperature. These calculations can be performed from 100% liquid to 100% solid phase of alloys at room temperature. The calculations begin by assuming 1 mole of each alloy. The results are evaluated according to the changes in the mole ratio of the phases to be examined depending on the temperature. In this way, the formation and dissolution temperatures, amounts of intermetallics, and all phases can be analyzed in detail, and this analysis guides aluminum casting applications. The phase analysis results of the alloys are given in Table 2. It is seen that the amount of eutectic-Si phase increases, while the amount of α-Al phase decreases with the increasing Si element for all alloys. According to ThermoCalc calculations, it was clearly seen that the amount of phase formed is directly dependent on the Si content. In virtual calculations, it was determined that with increasing Si amount, the amount of α-Al phase decreased, while the amount of eutectic-Si phase increased.

Table 2.
Phase ratios determined in microstructural examinations in a virtual environment after the solidification process at 25 °C (mol)

	Virtual results (mol)	
Alloy	**α-Al**	**eutectic-Si**
AlSi5	0.96339	0.02495
AlSi7	0.94413	0.04420
AlSi9	0.90992	0.08507

It is important to determine the critical temperatures and phase transformations in the casting process. Therefore, the temperature-dependent phase transformations diagrams including solidus and liquidus temperatures of the aluminum wheel alloys used in this study were estimated by ThermoCalc and JMatPro. The results are given in Figure 1. When the results obtained from the JMatPro were examined, it was observed that the melting point of the alloys decreased depending on the increase in Si concentration. The liquidus temperatures obtained by virtual calculations for AlSi5, AlSi7, and AlSi9 alloys are 630, 616, and 602°C, respectively. While there was a significant decrease in liquidus temperatures with the increase of Si content, no remarkable difference was observed in solidus temperatures as seen in Figure 1.

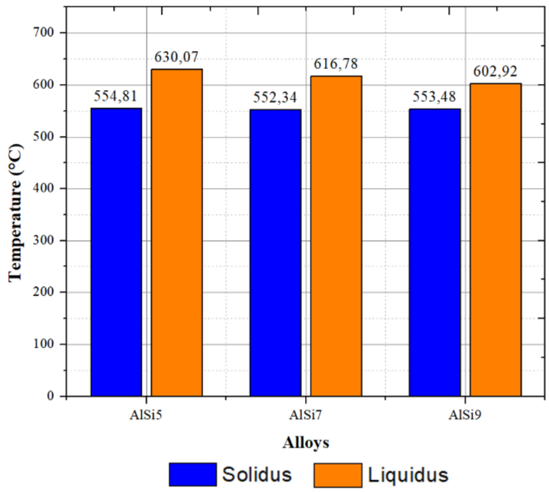


Fig. 1. Solidus and liquidus temperatures of the alloys calculated with JMatPro software

In addition, it is possible to obtain the detailed graphical results of temperature-dependent solidification analysis of alloys with ThermoCalc software. Analyzes are carried out with thermo-kinetic calculations, which are started from above liquidus temperatures (800°C), at 5°C intervals up to 25°C. The graphs of solidification analysis of AlSi5, AlSi7, and AlSi9 alloys are given in Fig. 2. In solidification analysis graphs, each phase is represented by a different colored line. As can be seen from Fig. 2, the α-Al phase called “FCC_A1” started to form in the structure with the decrease in temperature, while the liquid phase is stable at high temperatures. Then, depending on the amount of Si in the alloys, eutectic-Si phase formation, which is called “diamond”, started in AlSi5, AlSi7, and AlSi9 alloys at 567, 570, and 575°C, respectively. Finally, when the temperature drops to 25°C, it is seen that the microstructure consists of α-Al and eutectic Si phases. Since the alloys are not heat-treated, the precipitates of the Mg_2Si phase have not yet formed and the Mg is homogeneously dispersed in the structure (Fig. 9). The eutectic reaction temperatures, the temperatures at which solidification initiates and is completed, and the solidification range values obtained through ThermoCalc software by using computational materials engineering methods are given in Table 2. When the numerical results of the solidification analysis are examined, it can be said that the changes in the Si content of the alloys do not affect the eutectic transformation temperature. On the other hand, it is clearly seen that it significantly changes the solidification range, which is one of the parameters that are important in casting. The solidification range is obtained by subtracting the temperature at which solidification is completed from the liquidus temperature at which the solidification process begins. In alloys with a narrow solidification range, the tendency to form microsegregation in the casting structure is lower. Microsegregation is another consequence of the compositional differences occurring during the solidification of alloys and is the change of concentration from the core outward within the solidifying grains [20]. When the alloys used in the study are examined, the alloy with the lowest solidification range is AlSi9. From AlSi5 alloy to AlSi9 alloy, the solidification interval value decreases from 73.1 to 31.8 with the increase of Si amount. In this case, it is possible to say that the tendency of microsegregation in the microstructure of alloys in casting and this negativity, which causes undesirable changes in alloy properties, decrease with the increase of Si content [21-23].

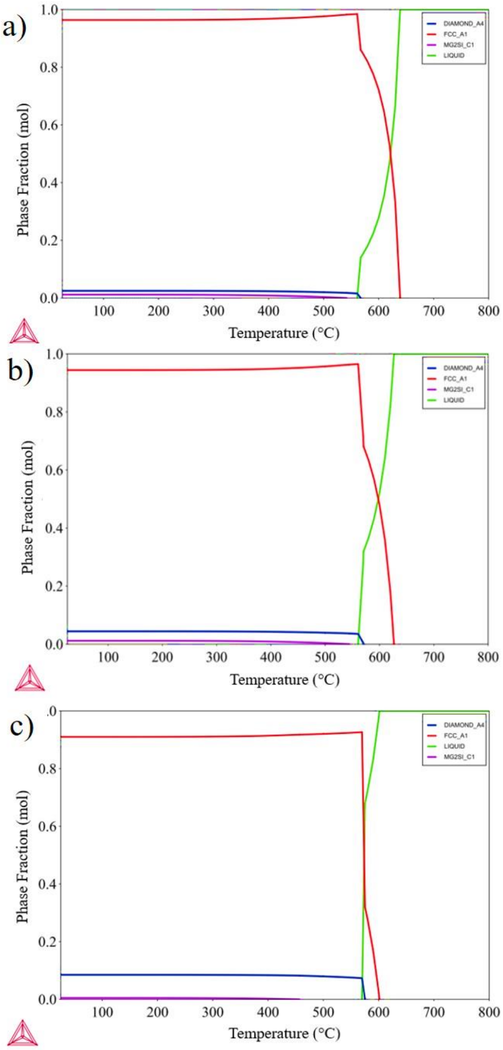


Fig. 2. Temperature-dependent phase fraction graphs of alloys a) AlSi5 b) AlSi7 c) AlSi9

Table 3.
Numerical data of solidification analysis graphs

Alloys	Eutectic teaction temperature (ºC)	Initiation temperature of solidification (ºC)	Solidification Completion Temperature (ºC)	Solidification Range
AlSi5	567.3	639.0	565.9	73.1
AlSi7	570.5	626.6	560.6	66
AlSi9	575.3	601.4	569.6	31.8

As a result of the JMatPro analysis, the mechanical properties of the alloys such as tensile and yield strength, elongation, and hardness were investigated. In addition, these mechanical properties were verified in the physical environment by the mechanical tests carried out in laboratory studies. The tensile tests were carried out to determine the yield and tensile strength values of the samples at least 3 times for each sample with Zwick Roell Z-100 model test device. The variation of the strength values of the alloys depending on the Si amounts is given in Fig. 3. In virtual calculations performed with JMatPro, it can be clearly seen that a certain amount of rise was found in the yield and tensile strengths values of AlSi5, AlSi7, and AlSi9 alloys with the increase of the Si amount. The yield strengths of the alloys are 83, 88, and 93 MPa, while the tensile strengths are 137, 145, and 152 MPa, respectively. JMatPro software can give graphically changes in the mechanical properties of the alloys in the casting state depending on the cooling rate. In this study, the cooling rate corresponds to approximately 2.08 °C/s when it is considered that the casting starts at 745 °C and ends at room temperature (25°C) and the cycle time is 5.45 minutes for the production of one wheel. Therefore, the yield and tensile strength values corresponding to the relevant cooling rate were taken into account and the revised Figure 3 was created in JMatPro software. On the other hand, magnesium is the main alloying element that affects the yield and tensile strength of aluminum-silicon casting alloys. The strength of the alloys is increased by the precipitation of the Mg_2Si phase in the microstructure after T6 heat treatment [24]. Si element, which is emphasized in the study, affects directly the mechanical properties of alloys such as tensile and yield strength. This result is similar to the studies in the literature examining the effects of silicon amount on mechanical properties in aluminum casting alloys [25-26]. These values obtained by CME activities are those for non-heat treated (as-cast) alloys and are as expected. Also, it can be interpreted that AlSi5 and AlSi9 alloys can be an alternative to AlSi7 alloy while considering these close strength values.

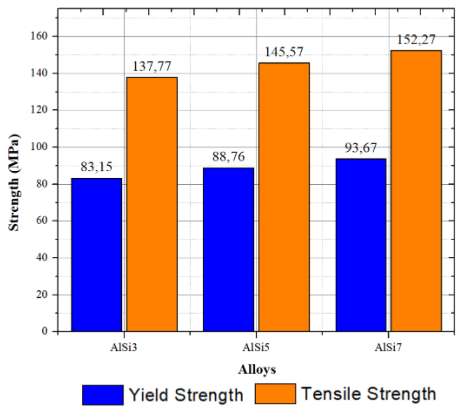


Fig. 3. The yield and tensile strength values of alloys in as-cast states with JMatPro

In addition to the microstructural characteristics and mechanical properties, it is possible to obtain temperature-dependent physical properties such as density and viscosity with JMatPro and ThermoCalc. In the first stage of solidification, the dendrites in the rosette structure fragment and form the final dendrite structure depending on viscosity. It was determined that the viscosity increased with decreasing temperature for each alloy. In different studies, it has been stated that the viscosity suddenly increases at a critical temperature point that the dendritic structure begins to form [27]. In this study, it was aimed to obtain a dendritic structure with the desired properties by controlling the metallic flow rate as industrially. Fig. 4 represents the variation of viscosity values depending on temperature. The variations of viscosity of the AlSi7 alloy depending on temperature during continuous cooling were determined using ThermoCalc software. In calculations, the alloys were cooled to room temperature starting above their liquidus temperature and viscosity values were obtained. When the alloys were compared with each other, it was observed that the AlSi9 alloy showed the highest viscosity values. In addition, it was determined that the viscosity values decreased depending on the decreasing amount of Si for all alloys. While the viscosity values for all alloys at 700°C are 1.266, 1.294, and 1.323 MPa.s, respectively, these values are 2.095, 2.091, and 2.092 MPa.s at 555°C. It is a fact that fluency generally increases as the composition of the alloy approaches the eutectic. On the subject, initial ideas were that changes in metal viscosity near the eutectic cause this. However, it is now known that this increase is due only to solidification behavior. When the viscosity is considered in many ways, it should not be shown as viscosity. In the physical sense, the viscosity of a liquid is related to the movements in the liquid [28]. Therefore, it has a certain value at a given temperature. The fluidity of the metal depends on two main factors, the metal properties and the variables of the test performed. Metal-related factors include viscosity, surface tension, surface films, gas content, residues, inclusion, solidification, and crystallization. There is a belief that liquid metals take quite different values in terms of viscosity and that poor and slow-flowing metal has high viscosity. In addition, it is an insignificant factor in castings as the fluid viscosity changes little with temperature [29]. For this reason, it is an expected result that the alloys used show close viscosity values and it can be said that the alloys will be alternatives to each other in terms of the casting process.

Density is another physical property that is as important as liquid viscosity in aluminum casting. The density of the Al alloy is one of the parameters that directly affect the weight of the final product. Since aluminum alloys are preferred mostly for vehicle lightening in the automotive industry, it is desired that the selected alloy has an as low density as possible without compromising its mechanical strength values. The changes in the density values of the alloys used in this study depending on the temperature were determined by using ThermoCalc software and the related graphics are given in Fig. 5. While the density values for AlSi5, AlSi7, and AlSi9 wheel alloys at 700°C temperature are 2.396, 2.404, and 2.412 g/cm^3, respectively, these values are 2.687, 2.680 and 2.672 g/cm^3 at 25°C. As can be seen clearly, below the solidification temperature, the density of all alloys decreased slightly with increasing Si content. This relationship was maintained up to the liquid-solid transformation temperatures but changed above the liquidus temperature. After this point, as the Si content of the alloys increased, the density values also increased. The small changes occurred in the density of the alloys at both high and low temperatures, as expected, since only the amount of Si changes in these alloys and the density is a physical quantity directly dependent on the elemental composition [30].

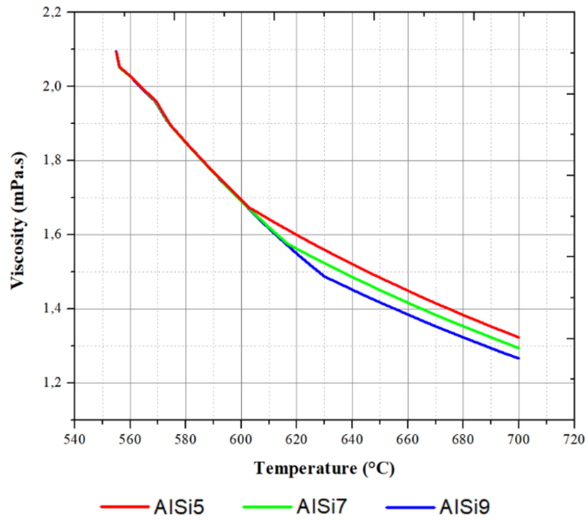


Fig. 4. Viscosity-temperature graphs for studied alloys

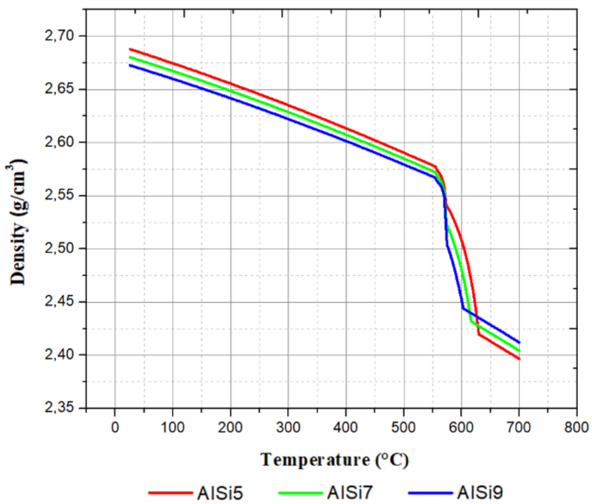


Fig. 5. Temperature-dependent density values graphs for studied alloys

3.2. Results of Test and Characterization Studies

3.2.1. Microstructural and mechanical examination

The properties of the samples obtained after industrial-scale pilot production studies were examined with the mechanical tests and characterization activities. The effect of Si amount on microstructural and mechanical properties of Al casting alloys was evaluated in lab-scale studies. The measurement of dendrite arm spacing (DAS) values in alloys was calculated according to the formula DAS=L/(n. V). Here, DAS shows the dendrite arm spacing value, L is the total arm length of the dendrites formed parallel to each other in the microstructure, V shows the microscope magnification value and n shows the number of dendrite arms in the analyzed region [31]. DAS measurements were calculated from at least 10 different regions for each sample and the average values were recorded. Also, the morphology and distribution of the α-Al and eutectic Si phases were analyzed under the optical microscope using advanced image analysis techniques. In Fig. 6. there are microstructural images taken from different regions such as a hub, spoke, and flange of each wheel sample and at 200x magnification.

When the microstructure images are evaluated, it is clearly seen that the amount of eutectic silicon phase (represented in dark color) in the structure increases with the increase in the amount of Si. During the solidification of Al alloys, pre-eutectic α-Al phase dendrites (represented in a light color) and in the interdendritic regions, the eutectic-Si phase is formed. In addition, the effect of AlTi5B1 master alloy added to the alloys to improve the mechanical properties with the grain refinement mechanism appears in microstructural studies. On the other hand, the effectiveness of AlSr10 master alloy added to the melt before the LPDC in order to change the morphology of the eutectic-Si phase from acicular to fibrous structure and to have a positive effect on the ductility of the alloy is clearly evident in the microstructures.

In addition, the phase distribution in the microstructure depending on the Si content of the samples was examined. Since the phase amount examinations are independent of different regions of the wheel and will not change according to the hub, spoke, or flange parts, evaluations were carried out only on the samples obtained from the hub region at least 5 measurements with 200x magnification. Accordingly, the green regions represent the α-Al phase and the blue regions represent the eutectic-Si phase. The results of the information about the increase in the amount of Si and the decrease in the α-Al phase are given in Fig. 7 by means of image analysis techniques in optical microscopy. As a result of the investigations, while the amount of α-Al phase was determined as 93.56%, 91.26%, 84.32%, and eutectic-Si phase were determined as 6.43%, 8.74%, and 15.67% in AlSi5, AlSi7, and AlSi9 alloys, respectively.

One of the microstructural examinations performed on the samples under the optical microscope is the measurement of the DAS values. The effect of the cooling process in aluminum casting significantly affects the DAS values and therefore the mechanical properties of the material [32]. The DAS values, which vary depending on the Si amounts of the alloys, were determined and the results are given in Fig. 8. Due to the increase in the cooling rate, the first fine-grained phase in casting is α-Al dendrites. Therefore, as the cooling rate increases, the distance between the dendrite arms decreases in line with the results obtained in the literature [33-35]. The more interlocked the dendrite network is formed in the microstructure, the higher the strength of the aluminum product. When the hub and flange parts are compared on a wheel, the cooling process occurs faster as the flange parts have a thinner section. For this reason, the DAS values calculated from the flange regions of the wheels are lower. In parallel with the mechanical examination results, yield strength values are slightly higher in regions that cool faster and have lower DAS values (Fig. 10 and Fig. 11). As a result, it was determined that DAS values decreased due to the increase in the amount of Si in the composition of the alloys.

The results of elemental mapping studies performed with the SEM-EDS module are given in Fig. 9. This analysis was carried out to determine the distribution of fundamental elements in the microstructure. In the examinations, colorations were chosen as gray for Al, red for Si, and green for Mg. As a result of the analyzes, it is seen that the eutectic silicon phase is located between the α-Al dendrites, and the area covered in the microstructure increases with the increase of the Si amount. In addition, since the alloys have not been heat-treated yet, the Mg element is homogeneously dispersed in the microstructure. When heat treatment is applied to the alloys, the Mg element will react with Si and form the Mg_2Si phase, forming precipitates in the structure. In that case, the Mg_2Si phase will be seen in the microstructure with small clusters as locally.

The mechanical values were obtained by tensile tests performed on samples taken from 3 different regions of the wheels. The samples of the tensile test performed to determine the yield, tensile strength (in Fig. 10), and elongation in (Fig. 11) values were obtained from the spoke, inner, and outer flange regions as specified in the DIN EN ISO 6892-1 standard.

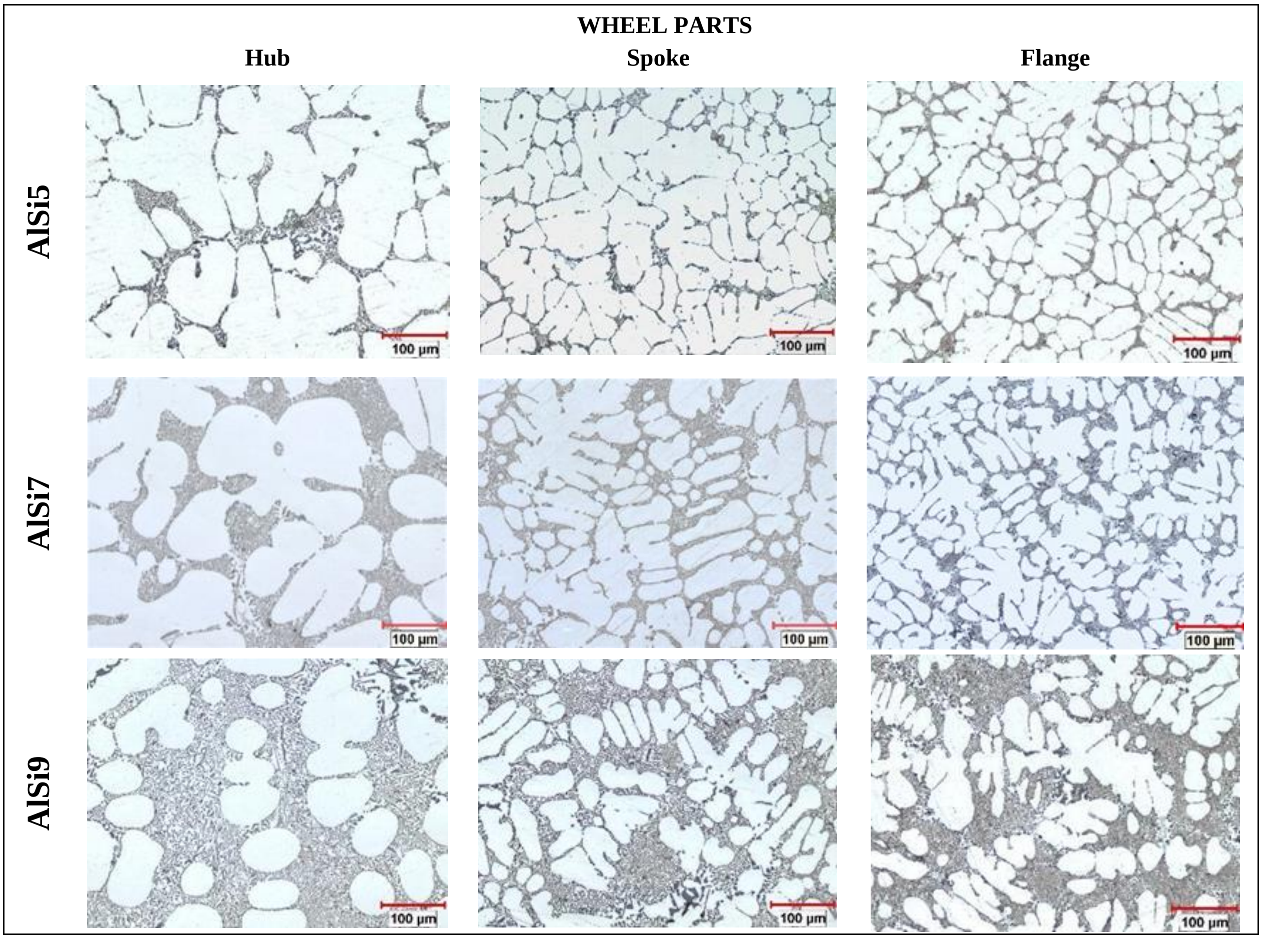
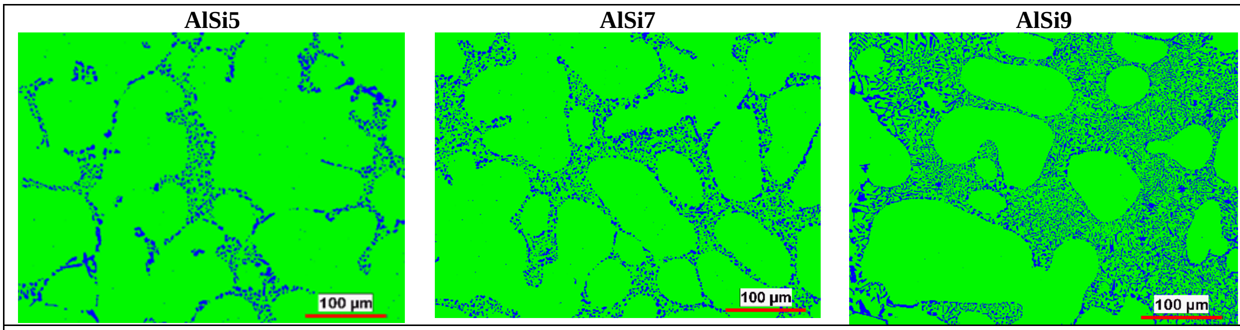


Fig. 6. Optical microscope images of the AlSi5, AlSi7 and AlSi9 alloys



α-Al (%)	93,56	**α-Al (%)**	91,26	**α-Al (%)**	84,32
eutectic-Si (%)	6,43	**eutectic-Si (%)**	8,74	**eutectic-Si (%)**	15,67

Fig. 7. Phase amount calculations for studied alloys

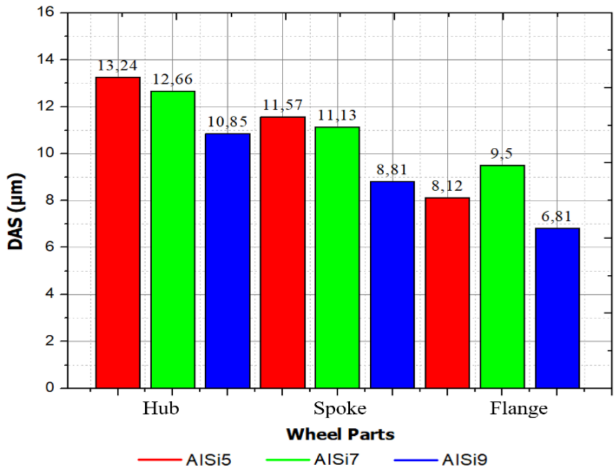


Fig. 8. DAS measurement results from different parts of the wheel

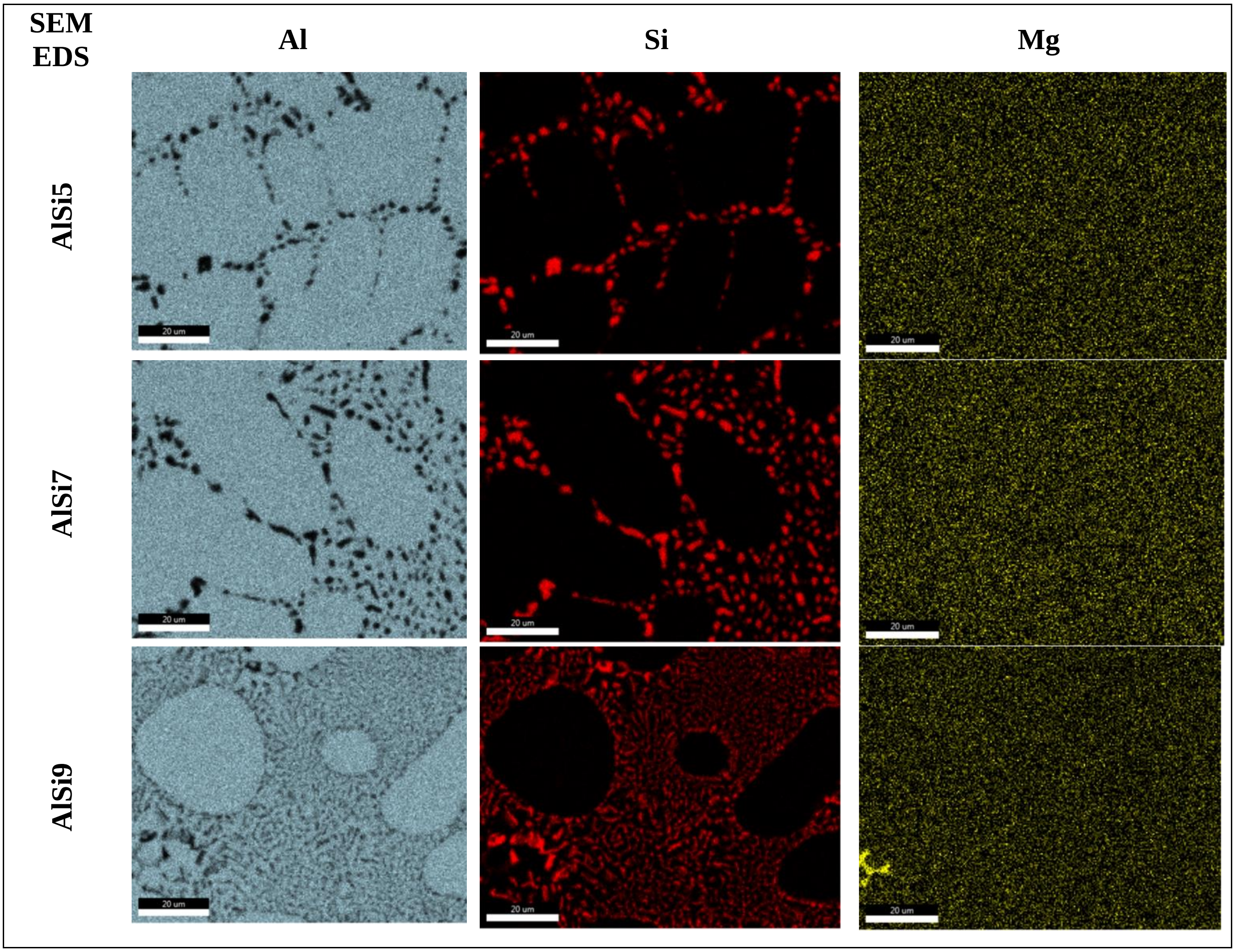


Fig. 9. SEM-EDS elemental mapping results for the alloys

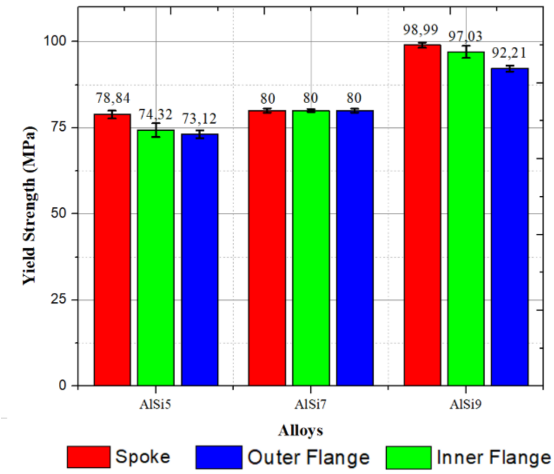


Fig. 10. Yield strength values from 3 different sections (Spoke, outer and inner flange) of the wheel samples

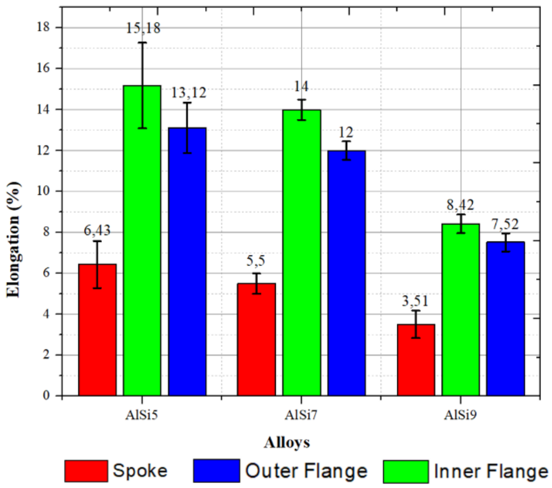


Fig. 11. Elongation values from 3 different sections (spoke, outer and inner flange) of the wheel samples

The hardness measurements of samples were carried out in accordance with ISO 6506 standard with an Emcotest hardness tester. Fig. 12 shows the evaluation of the hardness of the samples. Hardness measurements were carried out by taking hardness traces from 11 different points on each wheel sample.

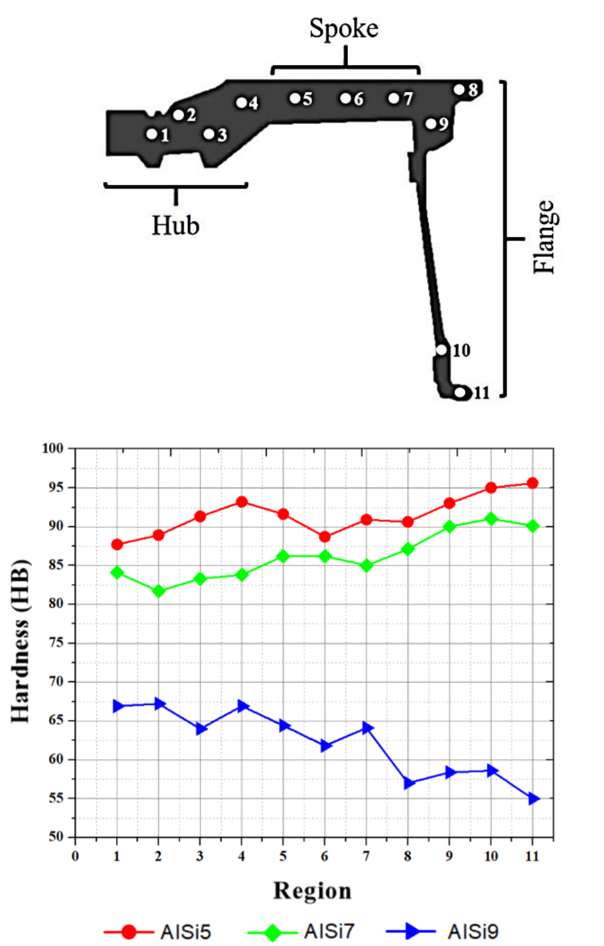


Fig. 12. Hardness values for AlSi5, AlSi7 and AlSi9 alloys and measurement points on the wheel section

4. Conclusions

The aim of this study is to develop aluminum casting alloys to be used in wheel production with LPDC by CME, which is one of the new generation metallurgical and materials engineering approaches. As a result of this study, it has been revealed that it is possible to obtain microstructural and mechanical properties of alloys that will affect product quality and performance properties before the casting process with CME studies. Data such as density, critical transformation temperatures, liquid viscosity, thermal properties, solidification analyzes of alloys that are critical parameters in the aluminum-based wheel casting process have been revealed with JMatPro and ThermoCalc. With this study, detailed information on the thermophysical, microstructural, and mechanical properties of alloys obtained as a result of real material analyzes based on the elemental compositions of the alloys has been presented to the attention of academia and industry for AlSi5Mg0.3 and AlSi9Mg0.3 alloys with hypo-eutectic composition and suitable for heat treatment, which can be an alternative to AlSi7Mg0.3 alloy used in aluminum wheel casting.

When the data obtained from virtual and industrial-scale pilot production were compared, it was concluded that the possible changes that may occur in the thermophysical, microstructural, and mechanical properties, even if the very small quantity, depending on the changing Si amount can be determined by CME studies before the mass production. Also, this approach is extremely important in industrial aluminum casting applications in terms of preventing material-based problems at the pre-design stage, improving the performance characteristics of the product, shortening the time to market, the competitiveness of the companies, and time management. From another point of view, with this study, an alternative alloy design method with computational materials engineering, which is a much more effective and economical way than the traditional trial-and-error method, which can be used in alloy, product, and process research & development studies is presented to aluminum alloy wheel manufacturers and academicians studying on this subject. Also, in this study, information about the capabilities of the CME software for the aluminum foundry industry is given.

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