Chapter

Characterization of Casting Properties of Rare-Earth Modified A356

Kerem Can Dizdar, Hayati Sahin, Furkan Tezer and Derya Dispinar

Abstract

Al-Si alloys are an attractive choice of light alloys due to their low density and high mechanical properties. The application areas include automotive and aerospace parts. With the increased requirements and demands on such applications, the researchers have focused on the enhancement of properties with the addition of novel alloying elements. In the last decade, modification of microstructure by rare-earth element additions has become popular. In this work, systematical tests were carried out by using fluidity test mold that has 8 arms with different thicknesses and tensile test mold that contains 10 bars to statistically analyze the mechanical properties. Different ratios ranging from 0.05 to 1 wt% of Er, Sc, Y, and V were added to Al-7Si alloys. The addition of 0.1 wt% Sc shows the highest fluidity whereas V additions have the lowest. Statistically, Sc addition revealed the highest reproducible results in terms of tensile properties where Y had the highest scatter. Er additions have the highest UTS and elongation at fracture.

Keywords: casting, A357, rare earth, tensile, fluidity, microstructure

1. Introduction

Grain refinement is a method used to alter the microstructure from heterogeneous dendrites into smaller and globular morphology. In this way, the casting properties are enhanced significantly. The feedability of the melt increases and thus fluidity increases. Since the interdendritic flow of the liquid resistance is decreased, the shrinkage and porosity decrease. Additionally, obtaining homogeneous and refined grains lead to achieving higher mechanical properties. It is important to note that the reduction of casting defects has the most determining influence on mechanical properties as well as the homogeneous distribution of secondary phases along with the microstructure.

Over the past several years, the modification of aluminum alloys with rare earth elements has gained great attention. The studies are concentrated on the improvement of mechanical properties by grain refinement or modification of Si morphology, particularly in Al-Si alloys. The use of Sc as a grain refiner has almost proven itself to be a key grain refinement agent. However, the expense of using Sc and the high cost have led the application to be limited. Alternative elements such as V, Y, Er, Eu and Ce have been started to be investigated in detail. Their refinement and modification effects have been found in Al–Si–Mg alloys [1–6].

Mazahery [7] investigated the effect of 600 ppm Eu addition to A360 on mechanical properties. It was found that as SDAS was increased, UTS was decreased by 25% and elongation at fracture was decreased by half. The microstructure and mechanical property change of A356 by Eu additions between 200 and 1000 ppm were investigated by F. Mao [8]. Eu was an effective Si modifier. The eutectic temperature was decreased, and Si morphology was altered from coarse plates into smaller fine spherical fibers which increased the tensile properties by 15% when 1000 ppm Eu was used.

L. Li [9] compared the semisolid die casting method to gravity casting. It was reported that 0.1 wt% RE addition had not affected the grain size but modification of Si to fibrous morphology had resulted in increased elongation at fracture for both methods. Increasing RE content to 0.4 wt% had resulted in the formation of needle-like intermetallic and the material had become brittle. Up to 0.8 wt%, Yb addition had formed globular primary and secondary dendrites with both Si and Fe intermetallic converted from acicular to finer morphology, however, higher amounts of addition of Yb to Al12Si had resulted in decreased mechanical properties [10]. Kabliman [11] added Sc to Al-Mg alloys to produce alternative foil material to Al-Cu alloys where 550 MPa was achieved at 0.5 mm thickness. Elgallad [12] found that in the absence of Sr., the addition of La and Ce to A356 and A413 had not modified Si, instead primary Si phases were formed. In the presence of Sr., much finer Si modification was observed. On the other hand, when Ti was added to these alloys, a high population of intermetallic formation was observed. When Yb was added together with La to A356, spherical Si particles were formed with a depression of 8°C of eutectic temperature [13]. M. Colombo [14] added different amounts of Er to A356 and showed that Er can both grain refine and modify Si at the same time. Best results were obtained at 0.3 wt% Er addition, and increased Er addition had resulted in the formation of intermetallic phases which decreased the ductility of A356 [15–17].

The effect of RE additions on the porosity formation of A356 alloy was investigated by Elgallad [18]. Various amounts of La, Ce, and La + Ce modifications were tried. When the intermetallic was increased (3%), the feedability was decreased which increased the shrinkage and porosity formation. On the other hand, it was reported that Ce was more dominant in pore formation than La. It was also found that Sr. was still the most effective modifier, but it also had a high affinity to RE elements possibly resulting in intermetallic formation [1]. Z. Wang [19] found that the addition of 0.1 wt% La and Ce increased the ductility of the alloy. The formation of fine and distributed secondary phases was observed on the fracture surface as dimples however in the absence of the RE added alloy, the fracture surface consisted of brittle cracks. Asmael [20] investigated the microstructure and mechanical properties of Ce added Al11SiCuMg alloy. Tensile strength and quality index were found to be the highest at 0.1 wt% Ce modified alloy. SDAS was decreased by 36%. When Ce content was changed between 0.5 and 1.0 wt%, it was found that there was no change in the microstructure and tensile properties. Pourbahari [21] studied the properties of thin-walled castings of A357 with La addition. La content was varied between 100 and 1000 ppm. The grain size was reported to be decreased by 50% with an increase of approximately 80% UTS. Sc additions up to 0.4 wt% revealed 50% decrease in SDAS of A356 with obtaining of spherical Si morphology [22]. Thus, the eutectic phase was increased from 40 to 45% with increased tensile property from 180 to 300 MPa. Yii [23] added Ce to Al20Si hypereutetic alloy and reported that wear properties were increased when 1.6 wt% Ce was added. Tzeng [24] added Sc to Al11Si and reported that beta-Fe intermetallic was converted to Chinese script which did not reduce the ductility of the alloy. The 0.8 Sc refined microstructure eliminated Fe-intermetallic formation increased tensile properties [25].

In this study, different amounts of Er, Sc, Y, and V were added to the A356 alloy. Efforts were made to statistically compare the effect of RE additions on the mechanical properties of A356 alloy. The reproducibility of tensile properties was investigated. The change in the fluidity of alloys was also investigated in the octopus design [26, 27].

2. Experimental

The chemical composition of the A357 aluminum casting alloy studied within the scope of the study is given in **Table 1** (Quantolux QLX3). Ten cylindrical bars were produced and cast into a sand mold where the dimension of bars was Ø8 by 160 mm (**Figure 1**). The weight of the charge to be melted was measured (approximately 15 kg) and melted in an ICS induction furnace in an A50 SiC crucible at 750°C. Reduced

Si	Fe	Cu	Mn	Mg	Ti	Al
7.485	0.173	0.021	0.018	0.529	0.126	91.45

Table 1.
Optical emission spectrometer analysis.

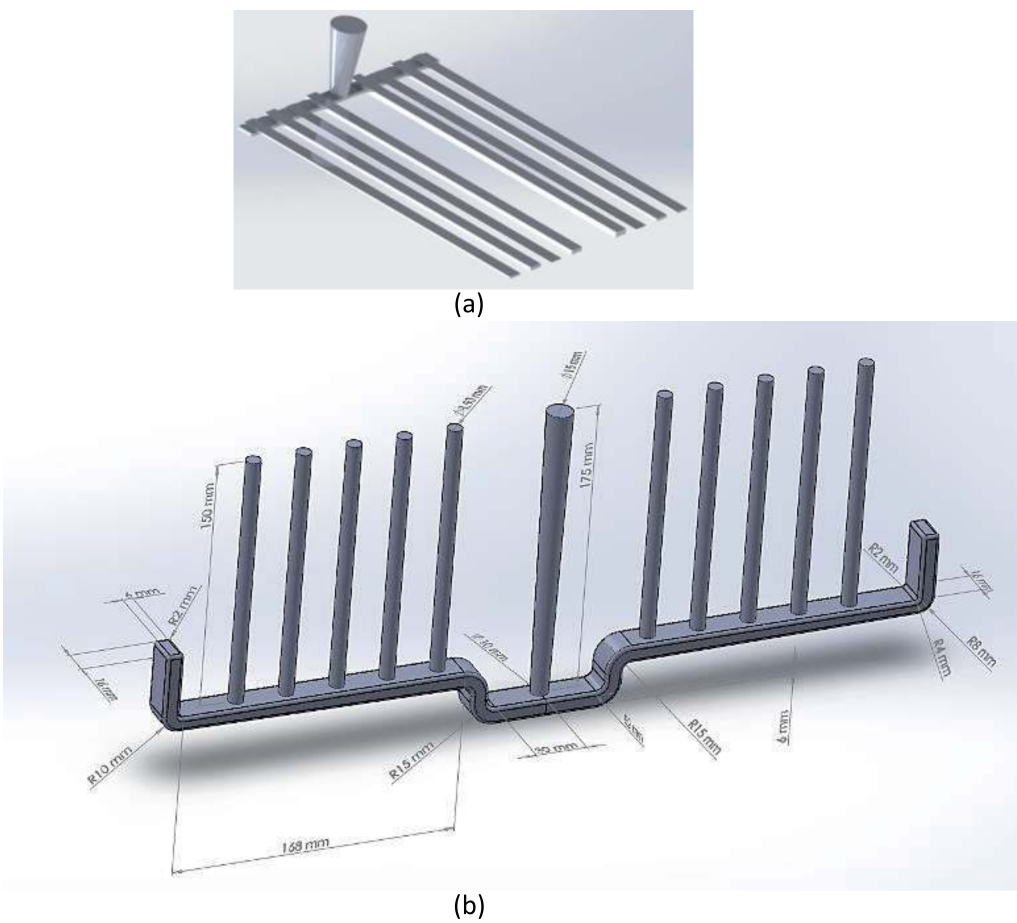

Figure 1.
Molds used for the characterization tests (a) fluidity (b) tensile bars.

pressure test samples were collected for measuring the melt cleanliness level. Ceramic diffusor lance was used where nitrogen gas was purged through the melt for the cleaning process.

The master alloys added to the melt were Al3Er, Al2Sc, Al5V and Al10Y. The weight % was aimed to achieve 0.05 and 0.1 in the alloy. Sand molds were prepared for the characterization tests. Octopus mold design [27] (**Figure 1a**) was used for fluidity characteristic where each arm had a length of 500 mm with thickness varying from 0.2 to 8 mm. Ten tensile bars were produced for each parameter where 10 mm diameter and 180 mm length cylinders were produced (**Figure 1b**). The molds were placed next to each other and after tensile bars were cast, the fluidity test mold was filled. This was repeated twice, and the same procedure was followed for each parameter to be able to have the same condition for each casting trial.

After the castings were complete, the samples were subjected to a heat treatment procedure [28] where the solutionizing was carried out at 540°C for 6 hours. The samples were then quenched in water (80°C) followed by 4 hours of aging at 145°C. Samples were machined according to ASTM E8/E8M standard and tensile tests were carried in Zwick Roell 8596. Weibull analysis was used to plot the survivability of the alloys studied in this work.

3. Results and Discussion

3.1 Tensile properties

The survivability plot is an indication of the lower and upper limits of any variable which gives the reliability and reproducibility of the data. In **Figures 2**–**4**, the tensile property changes of Sc, Er, Y, and V added A357 in as-cast conditions are given. For the yield strength (**Figure 2**), 0.05 and 0.1 wt% Sc reveal the highest reproducible results where the strength value changes between 116 and 120 MPa. In terms of design parameters, the survivability plot gives information about the possible lowest and highest potential values that this parameter can provide. For

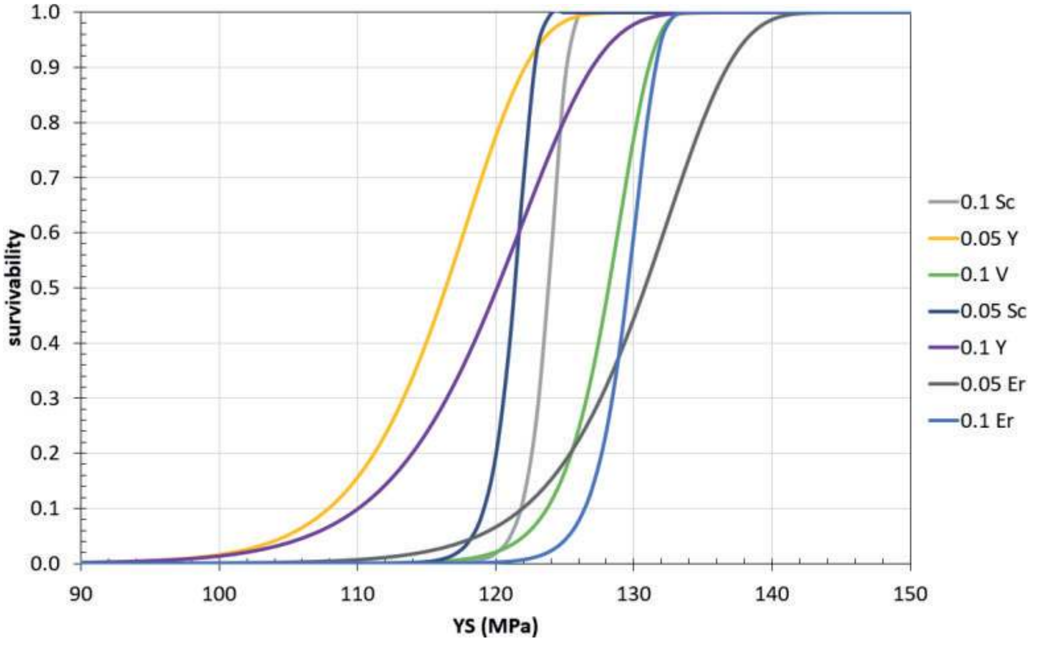

Figure 2.
Survivability plot of yield strength.

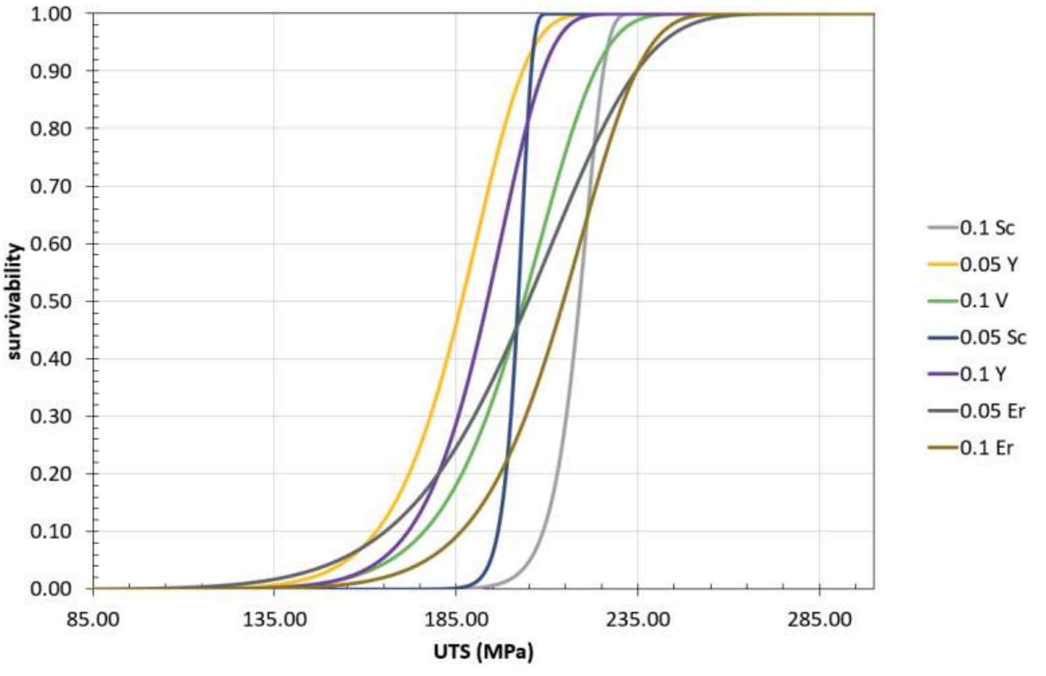

Figure 3.
Survivability plot of ultimate tensile strength.

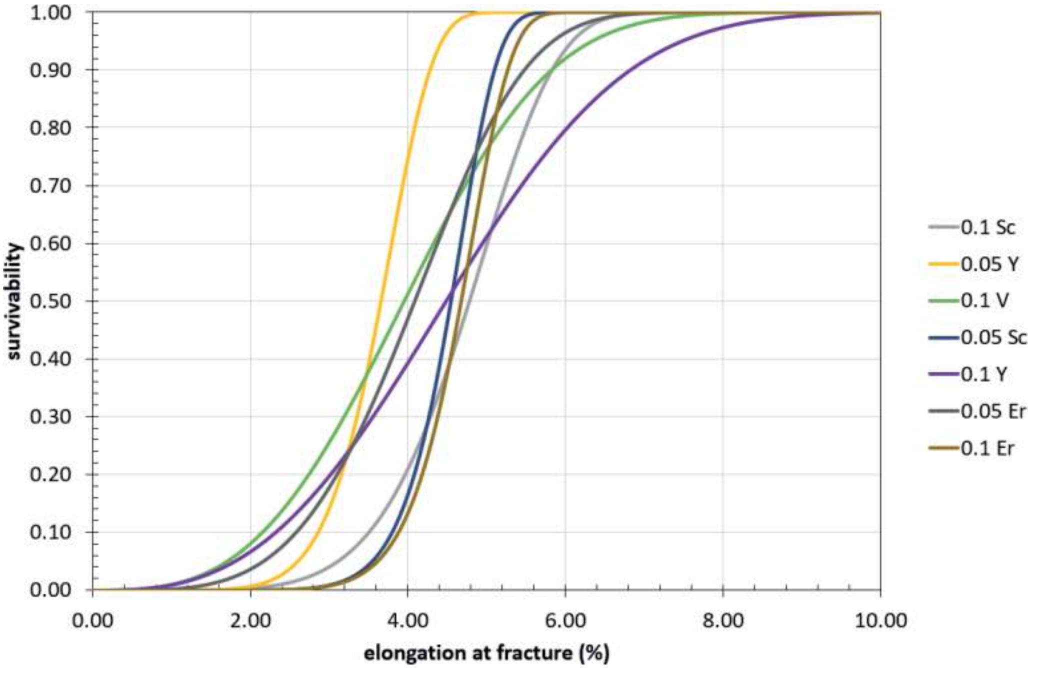

Figure 4.
Survivability plot of elongation at fracture.

example, 0.05 wt% Er castings reveal that they can exhibit a minimum of 109 MPa below which the material will always be in an elastic region. This particular test result also provides the information that this alloy can provide a yield strength of 140 MPa as well. Thus, it shows the potential of the alloy. However, since the scatter is too high (yield strength ranging between 109 and 140 MPa), the reliability of this parameter becomes very low. On the other hand, looking at 0.05 wt% Sc addition, it is very steep at values between 116 and 120 MPa which is quite narrow and thus the reliability of this casting is too high. This states that the yield strength value will undoubtedly be between these values.

The highest scatter is observed with 0.05 wt% Er and 0.1 wt% Y additions. The values are in the range of 90–133 MPa for Y, and 107–140 MPa for Er. Although, Er shows high scatter, yet it had the potential that this addition has the highest yield strength value of 140 MPa. On the other hand, the lowest yield strength value was obtained when Y was used as a modifier to A357.

The ultimate tensile strength values for all additions were very close to each other (**Figure 3**). The highest reliable and most reproducible results were obtained with 0.05 wt% Sc samples which were 197 MPa with a standard deviation of ±3. Pramod [22] had found that Sc additions to A356 had increased the UTS 45% when Sc was added up to 0.4 wt%.

The highest scatter was observed 0.05 wt% Er castings. The lowest UTS values were found to be in Y modified alloy whereas the highest possible UTS values were obtained with 0.05 and 0.1 wt% Er added A357 with a potential of having 265 MPa. Colombo [14] reported that 0.3 wt% Er addition was the optimum ratio in their study to exhibit the highest tensile properties.

As can be seen in **Figure 4**, 0.1 wt% Y added A357 had the potential of having 9% elongation at fracture, however, this alloy has the highest scatter and thereby revealing the least reliable casting. The 0.05 wt% Y added A357 has the lowest elongation while 0.05 and 0.1 wt% Er show the highest reproducible results.

The change in the tensile properties after the samples were subjected to heat treatment is given in **Figures 4–9**. There is almost twice the change in yield strength after heat treatment with Sc showing the highest value of 260 MPa and Y showing the lowest of 216 MPa (**Figure 5**). The ultimate tensile strength increases approximately 25% where Sc and Er have the highest value of 300 MPa whereas Y additions show the lowest UTS of 240 MPa (**Figure 6**). There is an almost 70% decrease in elongation values for all additions, except Er additions. Therefore, the toughness change of Er with and with heat treatment is nearly too small and Er additions exhibit the highest toughness amongst the alloys studied in this work (**Figure 7**).

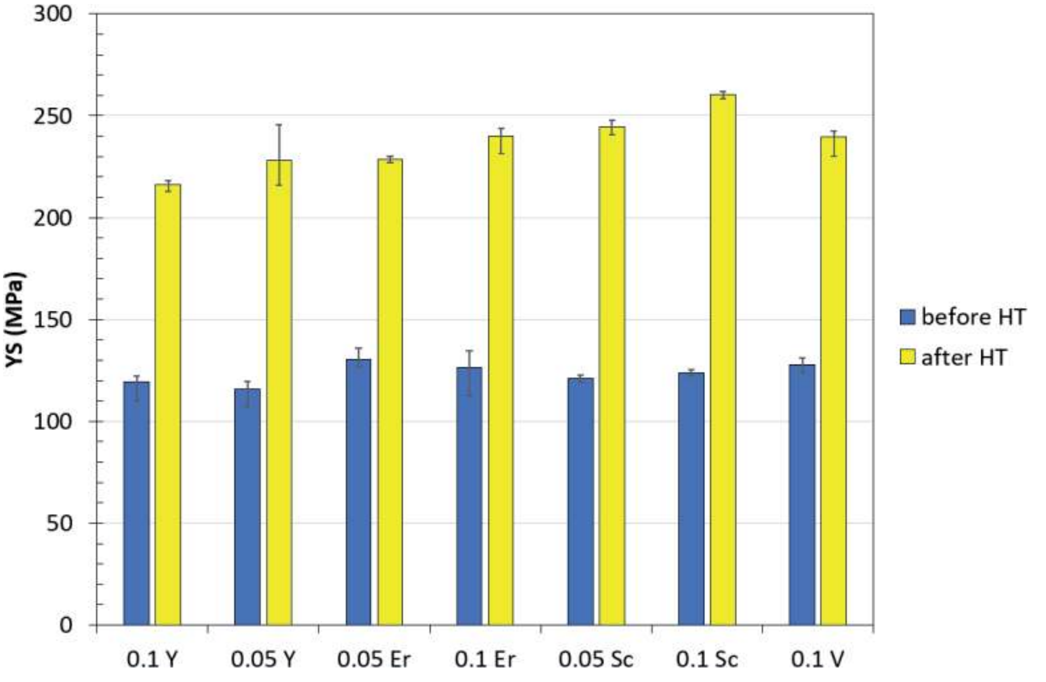

Figure 5.
Yield strength change with heat treatment.

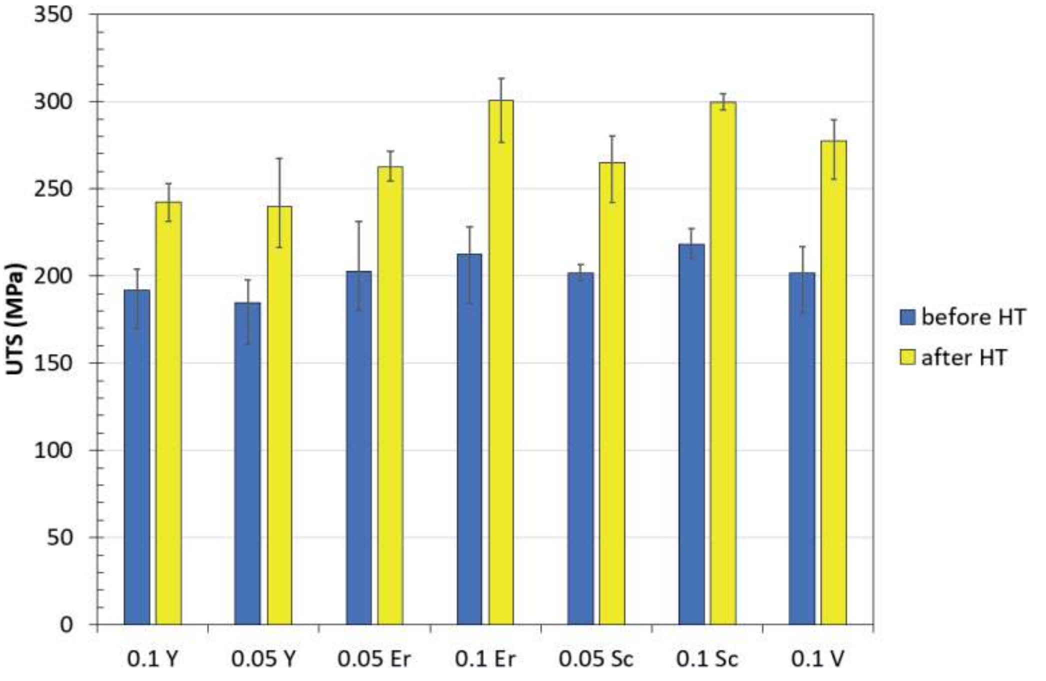

Figure 6.
Ultimate tensile strength change with heat treatment.

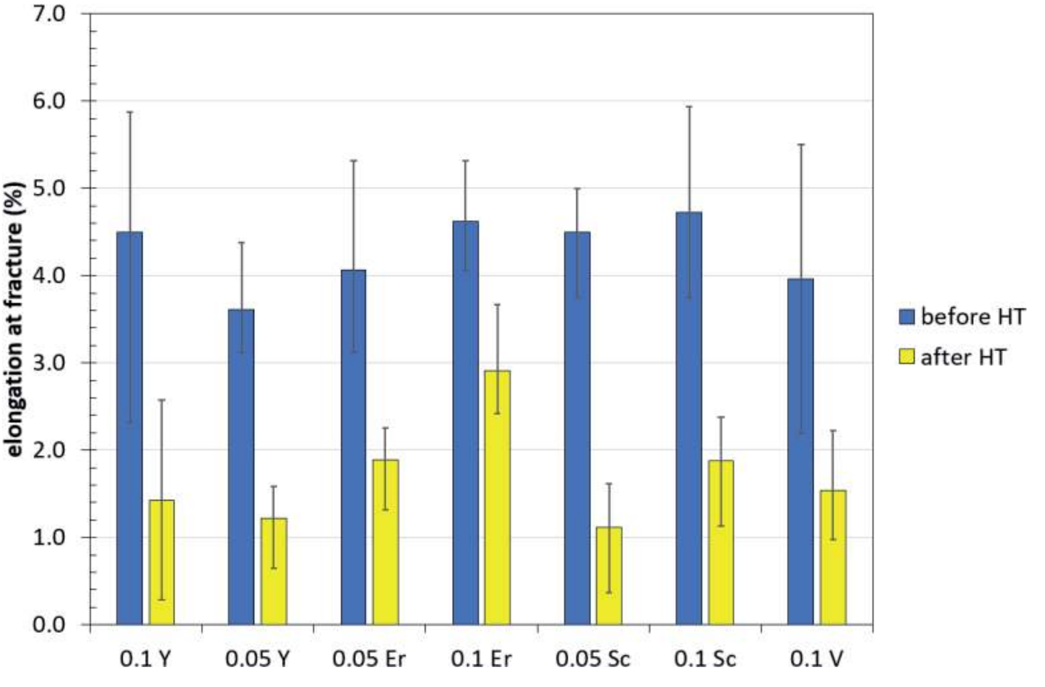

Figure 7.
Elongation at fracture change with heat treatment.

Hu [29] used the HPDC method to check the mechanical properties change of Al12Si alloy where Er content was changed between 0, 0.3, 0.06, and 0.9 wt%. It was reported that as Er content was increased, UTS was increased with decreased grain size, however, elongation at fracture values was decreased. This was attributed to the presence of Al_3Er phases found on the SEM images of fracture surface analysis. Therefore, it was concluded that these precipitates acted as reinforcements to the matrix, thus increasing UTS but decreasing elongation. Gao [16] reported

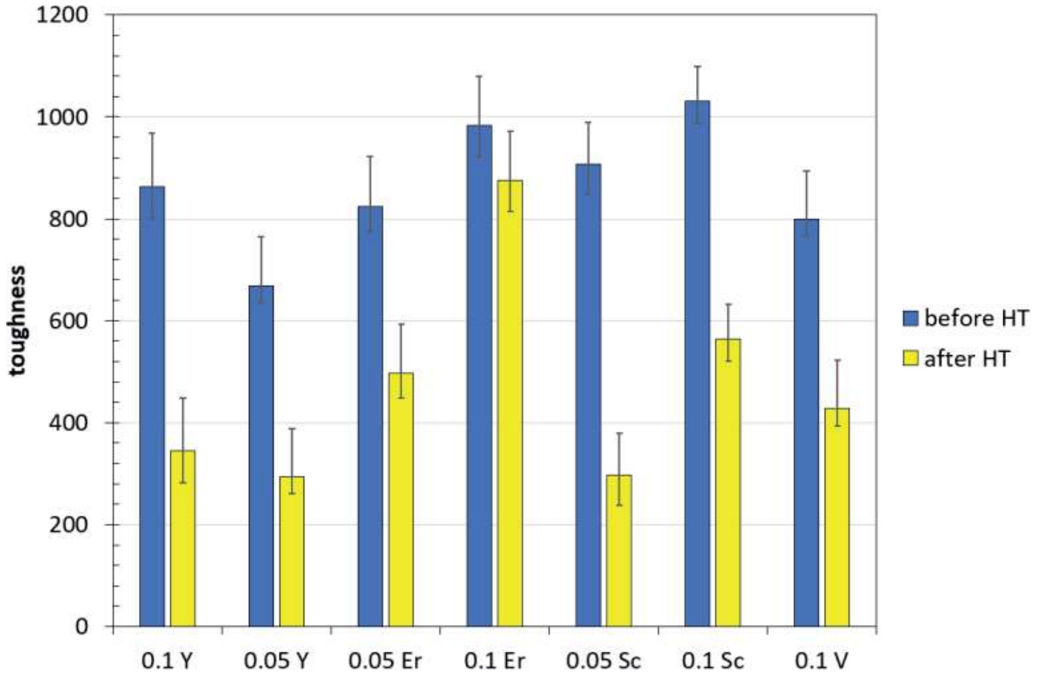

Figure 8.
Toughness change with heat treatment.

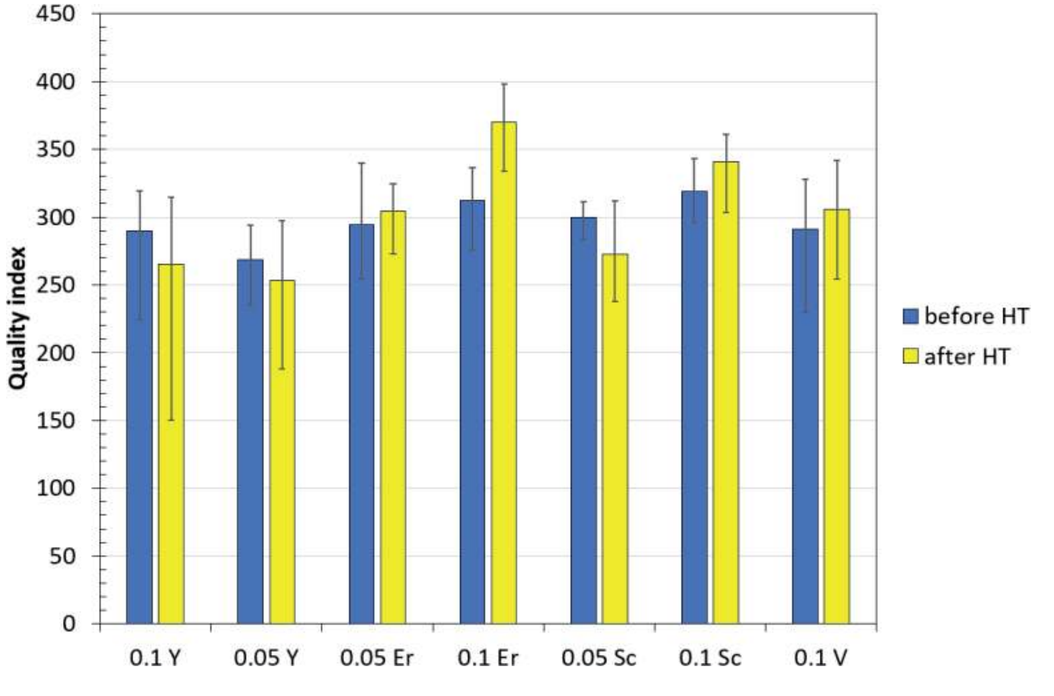

Figure 9.
Quality index change with heat treatment.

similar results claiming that nano-sized Al3Er, Al3Zr, and Al3(Zr,Er) precipitates show resistance to dislocations and increase the strength of pure aluminum significantly. Shi [15] proposed that Al3(RE) intermetallic phases do not have the grain refinement effect but rather act as barriers to dislocation movement and thereby increase the tensile properties of Al-Si alloys. Shi [15] also reported that Er has more physicochemical activity than that of other modifiers which have the potential to eliminate bifilms [27, 30–36] and increase the melt quality, therefore exhibiting higher mechanical properties. In the trials reported by Pramod [22], 0.4 wt% Sc addition to A356 had resulted in achieving 300 MPa levels with the lowest SDAS (10 μm) and refined Si morphology. In this work, 30 μm SDAS was good enough to achieve 300 MPa.

Pourbahari [21] studied the effect of La addition and they reported that the presence of intermetallic like Al_4La was more spherical and distributed in the microstructure (at low levels of La addition), and therefore they did not act as stress rising locations that would decrease the ductility of the alloy. However, when La content was higher than 0.1 wt%, new intermetallic phases such as AlSiLa were formed which were flakey and needle-like, thereby reducing the toughness of the matrix. The fracture surfaces were quasi-cleavage facets and not dimple like as in low La levels.

Drouzy's quality index [37] assessment was also used in this study and the results are given in **Figure 9**. It can be seen that Er and Sc both have the highest index values. Additionally, those elements are the only ones that show an increase in the quality index after heat treatment.

3.2 Microstructure

Although, the mechanical properties of each different grain refiner addition show a wide range of values and there is a quite difference between the samples, yet the microstructural analysis had revealed that the DAS and SDAS of all castings were very close to each other (**Figures 10** and **11**). Only 0.05 wt% Y addition shows the highest DAS value compare to the others, but all SDAS measurements of castings were recorded to be between 30 and 40 μm as seen in **Figure 12**. It is interesting to note that only in Y additions Si morphology was altered to fibrous type (**Figures 10b** and **11b**). Colombo [14] added 0.2 and 0.4 wt% Er and found that Er acted as a modifier for Si

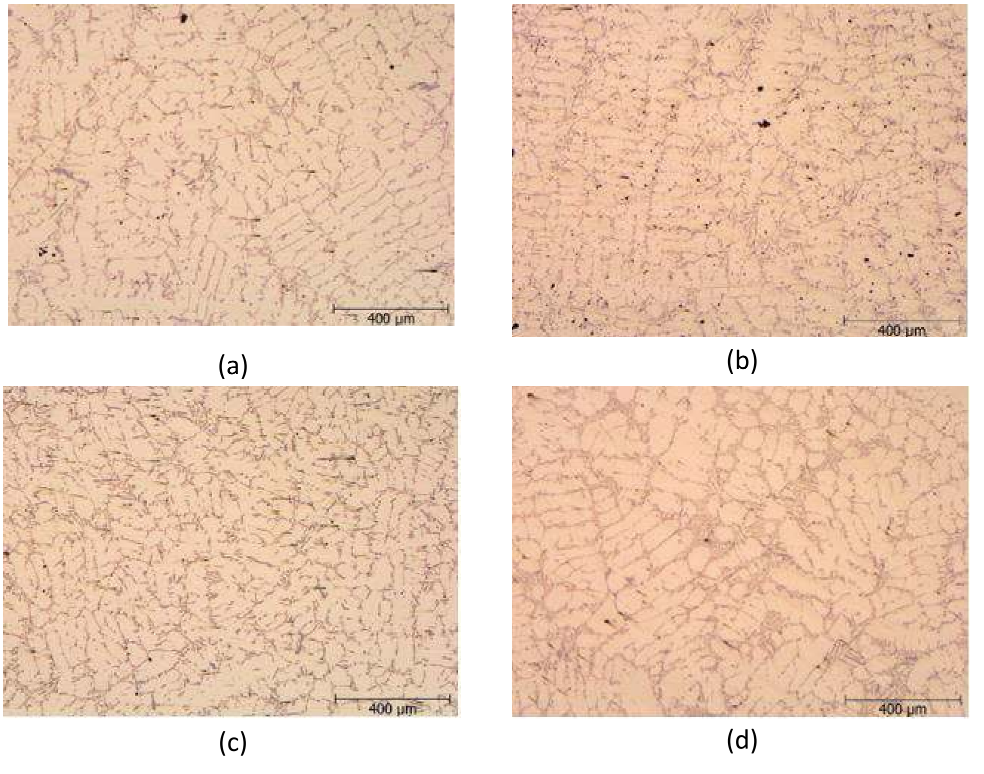

Figure 10.
Microstructures of 0.05 wt% (a) V, (b) Sc, (c) Er and (d) Y added A356.

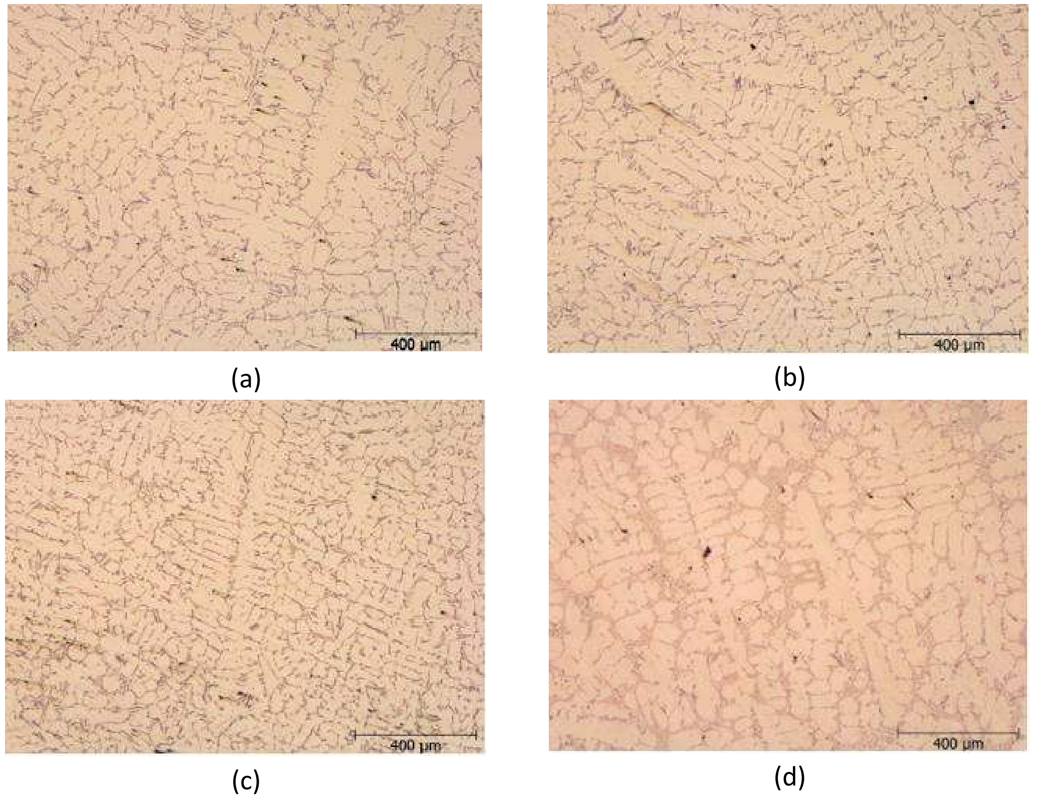

Figure 11.
Microstructures of 0.1 wt% (a) V, (b) Sc, (c) Er and (d) Y added A356.

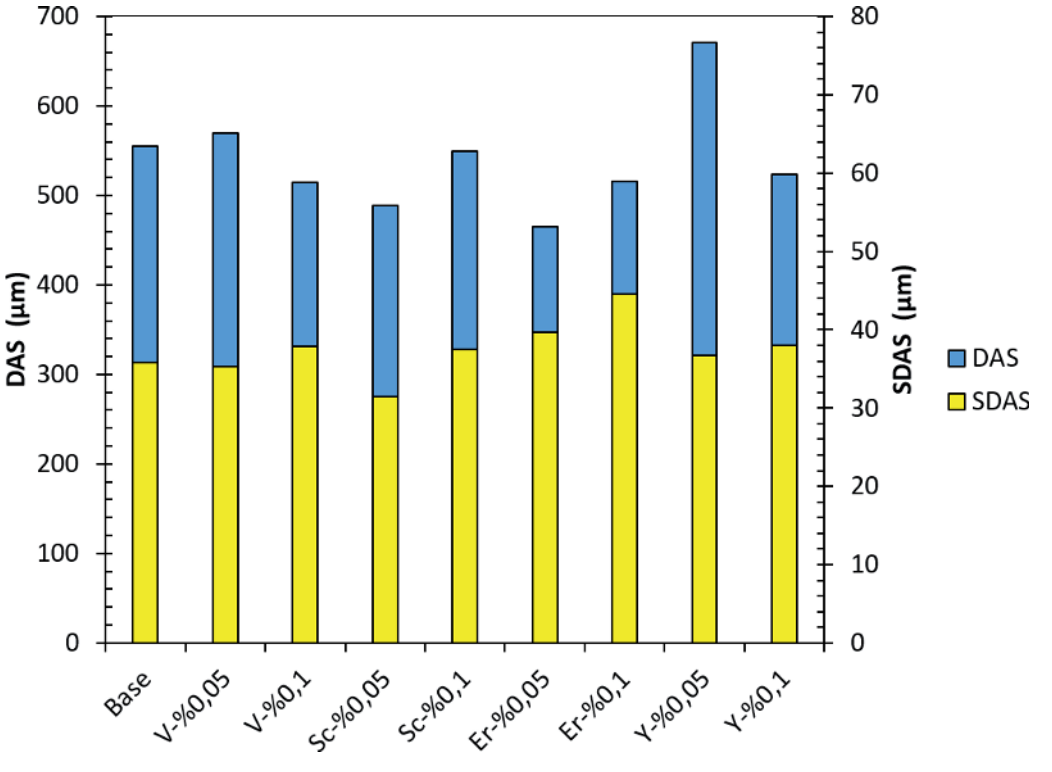

Figure 12.
DAS and SDAS change of different alloying element additions.

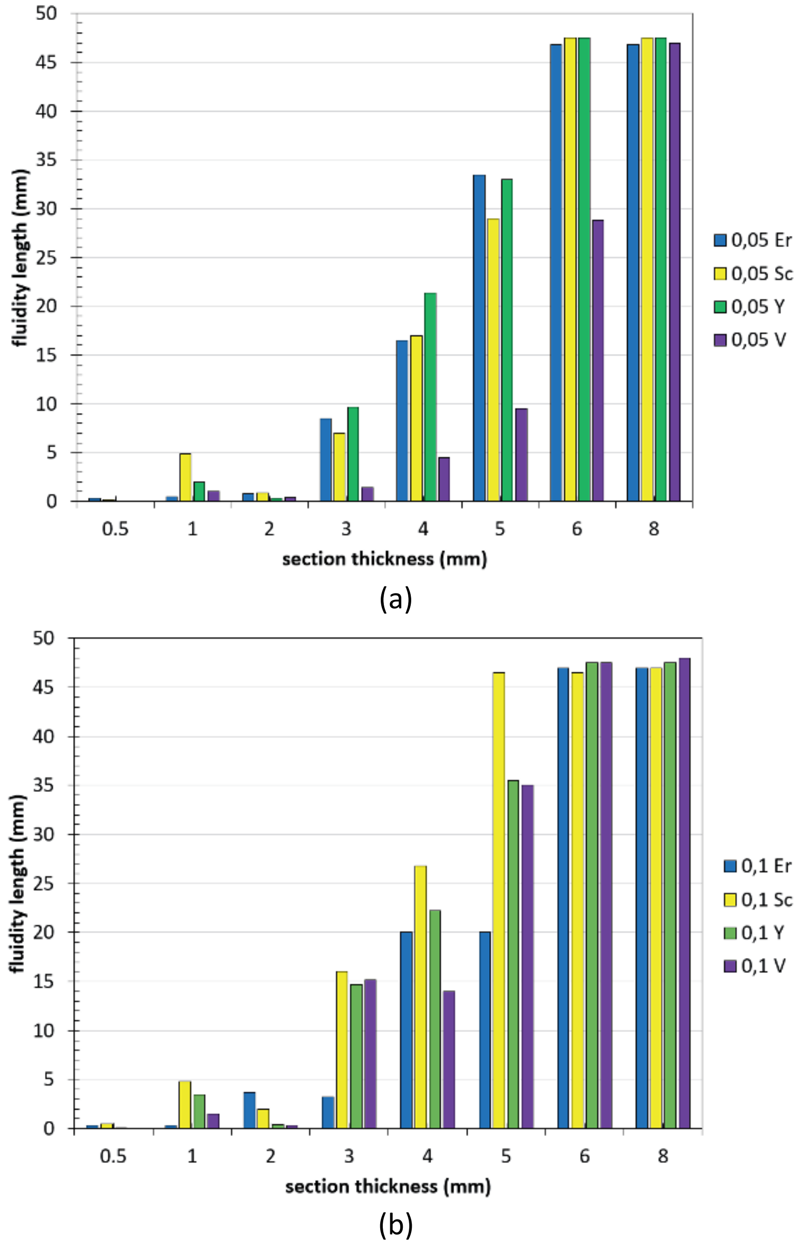

Figure 13.
Fluidity change of different grain refiner (a) 0.05 wt%, (b) 0.1 wt% additions.

together with a 30% reduction in SDAS. However, in this work, 0.05 and 0.1 wt% Er were added and no modification of Si was observed (**Figures 10c** and **11c**).

Pramod [22] reported that 0.4 wt% Sc had a reduction capability of SDAS by 50%. Compare to 0.2 wt% Sc addition, the silicon size was also significantly decreased which resulted in having the highest UTS values of 300 MPa. Pandee [38] added three different levels of Sc to A356; namely 0.24, 0.40, and 0.65 wt%. Two different cooling rates were studied. At both cooling rate levels (0.1 and 3°C/s), as Sc content was increased, Si morphology was modified to a fibrous structure. At 3°C/s, the modification of Si was found to be the optimum for 0.4 wt% Sc modified A356. In a similar kind of work, W. Zhang [4] also reported similar findings that higher than 0.15 wt %Sc addition to A356, Si morphology was completely modified.

On the other hand, Xu [25] found almost a linear decrease in grain size with increased Sc content varying from 0.2 towards 0.8 wt% Sc additions to F357 where the modification of Si was started at 0.2 wt% additions. With UTS values as high as 350 MPa.

3.3 Fluidity

The fluidity test results were analyzed under the wt% additions as seen in **Figure 13**. When 0.05 wt% addition levels are compared, it can be seen that Er and Y appear to have higher fluidity lengths compared to the other additions. On the other hand, when 0.1 wt% additions are analyzed, Sc has significantly higher fluidity compared to the other additions. In each of the cases, V reveals the lowest fluidity results. Prukkanon [39] reported that up to 0.2 wt% Sc addition, the fluidity of A356 was increased, but a higher amount of Sc addition had not affected the fluidity and remained unchanged at 660, 690, and 720°C.

4. Conclusion

The addition of 0.1 wt% Sc exhibits the highest fluidity in all cross-sections ranging from 0.5 to 8 mm thicknesses whereas V addition shows the lowest fluidity.

Although, the microstructural changes are not so significantly different from each other (all additions have SDAS values in the range of 30–40 μm), in terms of tensile properties, Sc addition to A357 alloy reveals the highest reliable and reproducible results. On the other hand, Y additions have the highest scatter with being the lowest reliable.

Before heat treatment, almost all additions have yield stress in the range of 119–130 MPa and ultimate tensile strength between 180 and 210 MPa. The addition of 0.1 wt% Sc has the highest UTS of 218 MPa which is quite closely followed by 0.1 wt% Er with a value of 212 MPa. Similarly, elongation at fracture values lie between 3.6 and 4.6% where Y is the lowest and Sc and Er is the highest.

After heat treatment, there are approximately two folds of increase in the yield strength for all additions. Y is the lowest with 210 MPa, and Sc and Er are the highest with 260 and 240 MPa, respectively. There is an approximately a 30% increase in UTS after heat treatment. Er is the highest with 300 MPa, followed by Sc at 299 Mpa. Y is the lowest with 240 Mpa. Elongation at fracture values were decreased dramatically after heat treatment from 4% towards 1%. Er shows the highest elongation with 4.9% while Y is the lowest with 1.2%.

In almost all additions, toughness value decreased after heat treatment, however, only when 0.1 wt% Er was added to A357, there was no difference in the toughness before and after heat treatment.

Author details

Kerem Can Dizdar[1], Hayati Sahin[1], Furkan Tezer[1] and Derya Dispinar[1,2*]

1 Metallurgical and Materials Engineering, Istanbul Technical University, Istanbul, Turkey

2 NonFerrous Metal Treatment, R&D Center, Foseco, Enschede, Netherlands

*Address all correspondence to: derya.dispinar@gmail.com

References

[1] Samuel A, Elgallad E, Mahmoud M, et al. Rare earth metal-based intermetallics formation in Al–Cu–Mg and Al–Si–Cu–Mg alloys: A metallographic study. Advances in Materials Science and Engineering. 2018;**2018**:1-15

[2] Jia K, Yu W-B, Yao J-M, et al. Al–9.00% Si–0.25% Mg alloys modified by ytterbium. Rare Metals. 2017;**36**:95-100

[3] Yun D, Zheng R, Xiaoping L, et al. Investigation on the modification behavior of A356 alloy inoculated with a Sr-Y composite modifier. Journal of Rare Earths. 2013;**31**:204-208

[4] Zhang W, Liu Y, Yang J, et al. Effects of Sc content on the microstructure of As-Cast Al-7 wt.% Si alloys. Materials Characterization. 2012;**66**:104-110

[5] Li B, Wang H, Jie J, Wei Z. Effects of yttrium and heat treatment on the microstructure and tensile properties of Al–7.5 Si–0.5 Mg alloy. Materials and Design. 2011;**32**:1617-1622

[6] Li J, Wang X, Ludwig T, et al. Modification of eutectic Si in Al–Si alloys with Eu addition. Acta Materialia. 2015;**84**:153-163

[7] Mazahery A, Habibnejad-korayem M, Takrouri K. Performance of europium in microstructural modification of high strength lightweight aluminum components. International Journal of Lightweight Materials and Manufacture. 2019;**2**:250-254

[8] Mao F, Yan G, Xuan Z, et al. Effect of Eu addition on the microstructures and mechanical properties of A356 aluminum alloys. Journal of Alloys and Compounds. 2015;**650**:896-906

[9] Li LF, Li DQ, Luo M, et al. Influence of Rare Earth Additions on the Microstructure and Mechanical Properties of Al7Si0.3Mg Alloys Processed by Semi-Solid Die Casting and Gravity Die Casting. Trans Tech Publ. 2019. pp 69-74

[10] Xiong J, Yan H, Zhong S, Bi M. Effects of Yb addition on the microstructure and mechanical properties of as-cast ADC12 alloy. Metals. 2019;**9**:108

[11] Kabliman E, Bozorgi S, Kronsteiner J, Nikolas A. Development of Al–Mg–Sc thin foils for fiber-reinforced metal laminates. Advanced Engineering Materials. 2019;**21**:1800462

[12] Elgallad E, Ibrahim M, Doty H, Samuel F. Microstructural characterisation of Al–Si cast alloys containing rare earth additions. Philosophical Magazine. 2018;**98**: 1337-1359

[13] Zhang S, Leng J, Wang Z, et al. Investigation on the modification behavior of A356. 2 alloy with Yb–La composite modifier. Materials Research Express. 2018;**5**:016520

[14] Colombo M, Gariboldi E, Morri A. Er addition to Al-Si-Mg-based casting alloy: Effects on microstructure, room and high temperature mechanical properties. Journal of Alloys and Compounds. 2017;**708**:1234-1244

[15] Shi Z, Wang Q, Zhao G, Zhang R. Effects of erbium modification on the microstructure and mechanical properties of A356 aluminum alloys. Materials Science and Engineering A. 2015;**626**:102-107

[16] Gao Z, Li H, Lai Y, et al. Effects of minor Zr and Er on microstructure and mechanical properties of pure aluminum. Materials Science and Engineering A. 2013;**580**:92-98

[17] Pengfei X, Bo G, Zhuang Y, et al. Effect of erbium on properties and microstructure of Al-Si eutectic alloy. Journal of Rare Earths. 2010;**28**:927-930

[18] Mahmoud M, Elgallad E, Ibrahim M, Samuel F. Effect of rare earth metals on porosity formation in A356 alloy. International Journal of Metalcasting. 2018;**12**:251-265

[19] Zhang X, Wang Z, Zhou Z, Xu J. Influence of rare earth (Ce and La) addition on the performance of Al-3.0 wt% Mg alloy. Journal Wuhan University of Technology-Materials Science Edition. 2017;**32**:611-618

[20] Ahmad R, Asmael M, Shahizan N, Gandouz S. Reduction in secondary dendrite arm spacing in cast eutectic Al–Si piston alloys by cerium addition. International Journal of Minerals, Metallurgy, and Materials. 2017;**24**:91-101

[21] Pourbahari B, Emamy M. Effects of La intermetallics on the structure and tensile properties of thin section gravity die-cast A357 Al alloy. Materials and Design. 2016;**94**:111-120

[22] Pramod S, Rao AP, Murty B, Bakshi SR. Effect of Sc addition and T6 aging treatment on the microstructure modification and mechanical properties of A356 alloy. Materials Science and Engineering A. 2016; **674**:438-450

[23] Yii SJ, Anas N, Ramdziah M, Anasyida A. Microstructural and mechanical properties of Al-20% Si containing cerium. Procedia Chemistry. 2016;**19**:304-310

[24] Tzeng Y-C, Jian S-Y. Effects of the addition of trace amounts of Sc on the microstructure and mechanical properties of Al-11.6Si alloys. Materials Science and Engineering A. 2018;**723**:22-28. DOI: 10.1016/j.msea.2018.03.016

[25] Xu C, Xiao W, Hanada S, et al. The effect of scandium addition on microstructure and mechanical properties of Al–Si–Mg alloy: A multi-refinement modifier. Materials Characterization. 2015;**110**:160-169

[26] Campbell J, Harding R. TALAT Lecture Notes: The Fluidity of Molten Metals. Lecture 3205. 1994

[27] Colak M, Kayikci R, Dispinar D. Influence of different cross sections on fluidity characteristics of A356. Transactions of the Indian Institute of Metals. 2015;**68**:275-281

[28] Sjölander E, Seifeddine S. The heat treatment of Al–Si–Cu–Mg casting alloys. Journal of Materials Processing Technology. 2010;**210**:1249-1259

[29] Hu X, et al. Effects of rare earth Er additions on microstructure development and mechanical properties of die-cast ADC12 aluminum alloy. Journal of Alloys and Compounds. 2012;**538**:21-27

[30] Dispinar D, Campbell J. Critical assessment of reduced pressure test. Part 1: Porosity phenomena. International Journal of Cast Metals Research. 2004;**17**:280-286

[31] Dispinar D, Campbell J. Porosity, hydrogen and bifilm content in Al alloy castings. Materials Science and Engineering A. 2011;**528**:3860-3865

[32] Dispinar D, Campbell J. Critical assessment of reduced pressure test. Part 2: Quantification. International Journal of Cast Metals Research. 2004;**17**:287-294

[33] Dispinar D, Campbell J. Use of bifilm index as an assessment of liquid metal quality. International Journal of Cast Metals Research. 2006;**19**:5-17

[34] Dispinar D, Campbell J. Effect of casting conditions on aluminium metal

quality. Journal of Materials Processing Technology. 2007;**182**:405-410

[35] Dispinar D, Akhtar S, Nordmark A, et al. Degassing, hydrogen and porosity phenomena in A356. Materials Science and Engineering A. 2010;**527**:3719-3725

[36] Uludağ M, Çetin R, Dispinar D, Tiryakioğlu M. Characterization of the effect of melt treatments on melt quality in Al-7wt% Si-Mg alloys. Metals. 2017;**7**:157

[37] Tiryakioğlu M, Campbell J. Quality index for aluminum alloy castings. International Journal of Metalcasting. 2014;**8**:39-42

[38] Pandee P, Gourlay CM, Belyakov SA, et al. $AlSi_2Sc_2$ intermetallic formation in Al-7Si-0.3Mg-xSc alloys and their effects on as-cast properties. Journal of Alloys and Compounds. 2018;**731**:1159-1170. DOI: 10.1016/j.jallcom.2017.10.125

[39] Prukkanon W, Srisukhumbowornchai N, Limmaneevichitr C. Influence of Sc modification on the fluidity of an A356 aluminum alloy. Journal of Alloys and Compounds. 2009;**487**:453-457