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A356.0 aluminum-silicon alloy is a base material for car rims application. Car rims are critical components for a vehicle as they carry the load of the passengers, goods, and the weight of the vehicle itself, therefore they should be sufficiently strong to withstand the vertical load, fatigue load, impact load, the side load and the braking force. Car rims are made by gravity die casting process. During the casting process, the inclusion of iron-content parts entering the molten Al can take place which leads to higher iron (Fe) concentration. High Fe con concentration lowers the toughness and the ductility of car rims. This study investigates the maximum value of Fe concentration that can be tolerated for acceptable mechanical properties of Al-Si alloy A356.0 for car rims application. The Fe concentration studied was 0.12 %wt, 0.16 %wt, and 0.20 %wt. Evaluation was performed on tensile as well as impact properties of the specimens. The test results show that increased Fe concentration decreases yield strength, elongation, and ultimate tensile strength (UTS). Furthermore, there is a quite large decrease in UTS (by 34 MPa) when Fe concentration increases only by 0.06 %wt. Impact strength decreases significantly from 15.47 to 2.91J/cm^2 as Fe concentration increases from 0.12 %wt. to 0.16 %wt. The porosity present in the casting is predicted to contributes to the ductility decrease. In addition, the decreasing value of UTS is predicted due to grain growth and dendrites formation. It is recommended that the maximum allowable Fe concentration for car rims application is 0.12 %wt.

Keywords: *Al-silicon alloy; car wheels; tensile properties; microstructure; gravity die casting*

1. INTRODUCTION

Nowadays various Al (Al) alloys are used for various engineering applications including in the transportation industry. Due to economic and technical consideration, lighter vehicle is required and regulated. One strategy to achieve the lightweight vehicle is by employing Al-based alloys for several auto parts, like the engine blocks and wheel rims. Al alloy A356.0 is used widely in aerospace and automotive application. Although Al alloy cannot be applied for heavy vehicle e.g. rims of bus and truck, aluminum-silicon (Al-Si) A356.0 is widely used for car rims application. The A356.0 alloy fits to be used for car rims since it shows good mechanical behaviors, i.e. high strength-to-weight ratio, corrosion resistance, and good castability. On the other side, car rims should show good resilient, resistant to side load or braking loads properties, have good tensile properties. According to Japan Industrial Standard (JIS) H 5202, material for car rims should possesses elongation > 5%, ultimate tensile strength (UTS) > 245 MPa, impact strength higher than 5.90 J/cm^2 [1]. These mechanical properties however cannot be achieved only by as-cast product. Thus, Al car rims must undergo heat treatment to achieve those mechanical properties. Alloying elements added to the molten Al during casting influence the mechanical properties and heat treatment ability of as-cast Al.

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Alloying elements added to the Al-alloy are classified as three main groups, i.e. basic alloying elements, additions in minor concentration, and impurities [2]. Depending on the nature of the elements, the similar elements could differently contribute. Major alloying elements that are usually present in the Al-casting are magnesium, silicon, copper, germanium, and silver since their maximum solubility in the Al alloys can be higher than 1 %wt. For example, concentration of manganese, copper and silicon in Al casting can be higher than 10 %wt. On the other hand, minor alloys that are present in Al casting are manganese (Mn), titanium (Ti), boron (B), and iron (Fe). Magnesium (Mg) increases mechanical properties of Al alloy particularly at high temperature [3,4]. Additionally, addition of Mg improves creep resistance. Therefore, Mg can be found in Al-alloy for high temperature applications, e.g. crank case, engine cooling fans, structural aerospace components, pistons, etc. Although Mn is present only in minor concentration in the Al casting, it has an significant effect to neutralize the detrimental effect of iron and to increase the thermal stability of Al casting [2]. For both in as-cast product and after T6 heat treatment of Al alloy A356.2. Higher Mn concentration up to 1.0 %wt was reported to increase ultimate tensile strength (Table 1) [5].

Table 1: Infuence of Mn concentration on mechanical properties of as-cast and after T6 heat treatment of aluminium alloy A356.2 [5]

Mn	UTS (kg/mm^2)		ELONGATION (%)		HARDNESS (HVN)		IMPACT STRENTGH (J/cm^2)	
%wt	CAST	T6	CAST	T6	CAST	T6	CAST	T6
0.05	16.24	25.14	10.18	8.72	54.26	80.27	6.35	6.07
0.2	18.34	27.56	9.53	8.34	58.32	83.74	6.24	6.02
0.4	20.12	29.46	9.36	8.12	62.33	86.46	6.21	5.97
0.6	21.68	30.58	9.53	8.04	66.32	88.74	6.22	5.95
0.8	22.25	32.38	8.33	7.98	70.44	89.24	6.23	5.94
1.0	22.28	33.58	8.27	8.14	74.32	93.74	6.28	5.92
1.2	22.23	32.83	8.21	7.12	73.26	92.16	5.96	5.88
1.4	22.18	31.58	8.43	7.54	71.32	90.74	5.24	5.86
1.6	21.85	31.45	8.78	7.67	70.36	90.46	5.12	5.82

Al-Cu alloys show higher yield strength and ultimate tensile strength (UTS) in a wide temperature range. This circumstance occurs due to the presence of Cu in Al which can result in a solid solution strengthening effect [2]. Moreover, Cu also causes significant dispersion hardening after Al-Cu alloy experiences quenching, solid solution heat treatment, and aging in as much as solubility of Cu in Al significantly decreases with increasing temperature. Unfortunately, corrosion resistance in Al casting decreases with addition of Cu [3].

Another major alloy in Al casting is silicon (Si). Al dissolves Si at maximum amount of 1.6 %wt (Figure 1). The eutectic point of Al-Si alloy occurs at concentration of 12.6 %wt Si and temperature of 557 ºC. Silicon is used in Al alloys for two main reason. The first reason is due to its high solubility in Al alloys. The second one is due to the formation of the (Al)+(Si) eutectic. This defines important Al–Si alloys' properties, e.g. strength and their castability [2]. Silicon increases the yield strength and UTS of Al-Si alloy since the load in α-Al matrix can be transferred to the rigid Si-plates [6,7]. Requena *et al*. [8] reported that Al-alloy has strong wear resistance and can be easily heat treated due to the presence of Si.

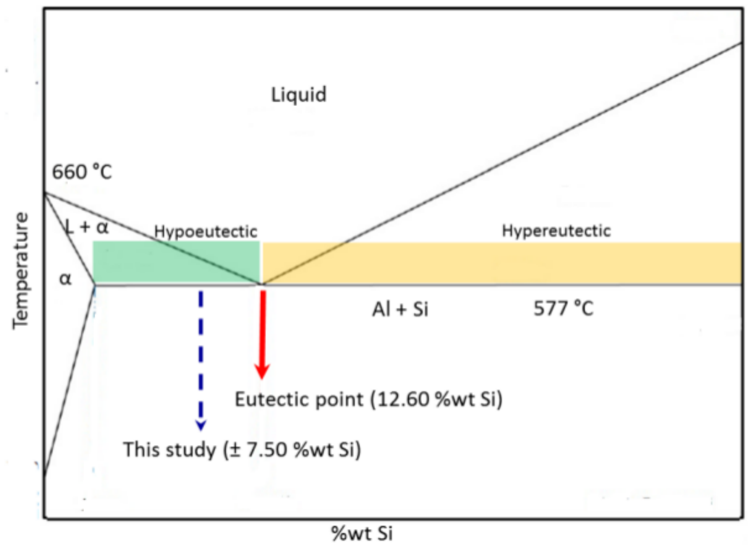

Figure 1. Al-Si phase diagram

Iron has a very limited solubility in the solid phase of Al alloy with a maximum value of 0.03 %wt. Fe increases hot tear resistance of as-cast product and reduces the tendency for die sticking or soldering of Al alloy in die casting [9]. Fe cannot form supersaturated solid solution although after a relatively rapid solidification. This rapid solidification causes the formation of excessive phases, i.e. constituent particles, which often decrease formability and corrosion resistance of Al alloy. In addition, the detrimental influences of higher Fe concentration are generally associated with the formation of Fe-containing intermetallic phase during solidification [10]. In Al-alloys, Fe shows tendency to combine with other alloy elements to form intermetallic phases. In the presence of Si, the dominant intermetallic phases are Al_8Fe_2Si, which is known as α-phas, and Al_5FeSi, which is known as β-phase, [11]. Moreover, π-$Al_8FeMg_3Si_6$ intermetallic phase is formed when Mg presents together with Si in Al alloy [12]. Zihalova and Bolibruchova [13] reported that higher "needle like" intermetallic phases Al_5FeSi, $Al_{15}(Fe,Mn)_3Si_2$ or $A_{18}FeMg_3Si_6$ were found with increasing Fe concentration.

Al alloy A356.0 contains 0.25 %wt Cu max, 0.20 to 0.45 %wt Mg, 0.35 %wt Mn max, 6.50 to 7.50 %wt Si, 0.6 %wt Fe max, 0.35 %wt Zn max, and 0.25 %wt Ti max [14]. This A356.0 shows good castability due to its low Cu concentration and high Si concentration [2]. Thus, the Al-cast shows good ability to fill the dies and solidifies without any hot tear or hot crack. The above previous works, i.e. [11,12,13], studied Fe concentration more than 0.20 %wt. On the other hand, several national car rim manufacturers informed that Fe concentration higher than 0.20 %wt in A356.0 alloy results in significant decrease in elongation and impact strength which is intolerable for car rims application. During casting process, the Fe concentration in liquid Al can increase due to several factors, e.g. mass transfer during contact between liquid Al and casting tools, furnace refractory, recycled scrap that are made from ferrous alloys. Taylor [11] reported that contact between liquid Al and gravity die casting can increase the iron concentration up to 2 %wt at 700 °C and increase up to 5 %wt at 800 C. This is due to higher mass transfer coefficient for Fe diffusion as temperature increases. Other sources of increasing Fe concentration in the molten Al are from accidentally fallen steel bolts to the melting furnace and other ferrous contained in added alloy during melting process.

This study therefore focused to investigate the impact strength and the UTS value of A356.0 Al-Si alloy as the effect of Fe concentration at 0.12 %wt, 0.16 %wt, and 0.20 %wt. Additionally, the correlation between microstructure of the alloy and the mechanical properties obtained was also evaluated. If the tolerated Fe concentration closes to 0.20 %wt, the car rims manufacturer receives an additional benefit since the use of expensive pure Al can be limited. To decrease Fe concentration, expensive pure Al should be added when excessive Fe concentration exists. Result of this study is expected to be used in a car rims manufacturer as a reference for the chemical composition of the liquid A356.0 alloy prior to pouring into the metal die. Should the Fe concentration in liquid A356 is higher than the reference limit; the liquid Al should be then further processed before pouring.

2. METHODOLOGY

The experiments were carried out in a national car rim company. A reverberatory furnace with 30 kg capacity was used to melt down the Al-alloy. This delivers advantage to the melting process since there was no contact between the molten alloy with air and combustion gas. This method was applied to prevent formation of Al-oxide since Al is easily oxidized by O_2 or CO_2 due to negative Gibbs energy of its oxidation [15]. Initially, a commercial Al-alloy with Fe concentration 0.11 %wt was used as the base metal. The A356.0 ingot was melted down at temperature up to 715 °C. This temperature was applied to suppress oxides and porosity formation. From the factory experience, more oxygen present in the liquid metal as temperature increases which can increase the oxide formation and gas porosity. When pouring temperature was reached, Fe was added to the Al liquid to obtain various Fe concentrations of 0.12 %wt, 0.16 %wt, and 0.21 %wt. Due to a very small difference in Fe concentration, Fe in the form of ferrous wire mesh was carefully added to the liquid Al.

After the addition of Fe in the molten Al-alloy, the liquid was stirred to homogenize and the chemical composition of the liquid alloy was analyzed using a mass spectrometer. If the chemical composition achieved the designed one, the liquid metal then poured into the metal die (Figure 2). The metal die was designed with a shape and dimension of tensile test and impact test specimens in accordance with JIS Standard Z2241 (Figure 3) and JIS Standard Z2242 (Figure 4) for tensile and impact test standard respectively.

The solidification in the metal die occurs at high cooling and solidification rate. A high cooling rate delivers advantage since the formation of secondary dendritic arm spacing can be suppressed [11]. There were 18 specimens prepared for tensile and impact testing. Three specimens were produced for each testing with a certain Fe concentration. Hardness test for all Fe concentrations was then worked out after both testing.

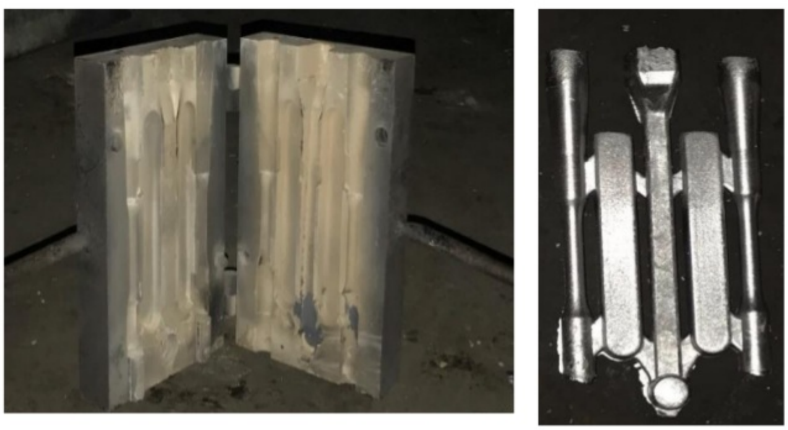

Figure 2. a) Metal dies for tensile and Charpy impact test specimen; b) The as-cast aluminium

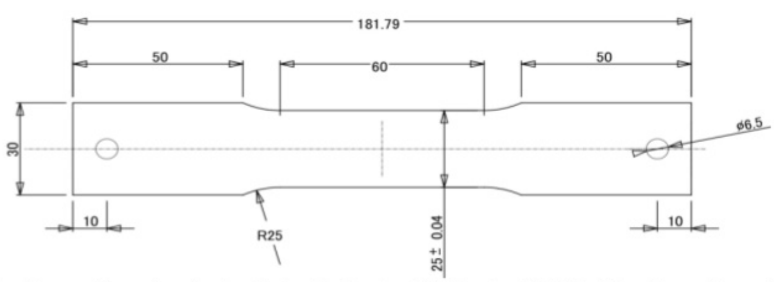

Figure 3. Specimens dimension for tensile test following JIS Standard Z2241 (all units are in mm) [16]

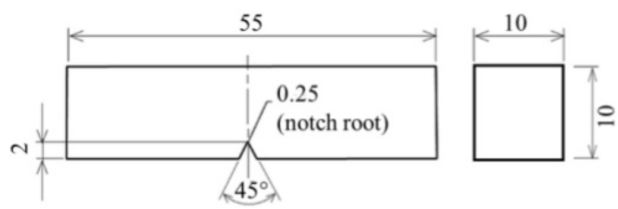

Figure 4. Specimens dimension for Charpy impact test following JIS Standard Z2242 (all units are in mm) [17]

3. RESULT AND DISCUSSION

The fracture surface of the tensile test specimens informs that as-cast A356.0 alloy tends to have a brittle behavior (Figure 5). This is also quantitatively confirmed by their elongation (Table 2 and Figure 6). The elongation for Fe concentration of 0.12 %wt, 0.16 %wt and 0.20 wt. % are 7.44%, 5.16%, and 4.57% respectively. The elongation for 0.20 %wt Fe concentration is below 5% which the permissible value as-cast aluminium according to JIS H 5202. The yield strength obtained decreases with the increase of Fe concentration, i.e. 128.33 MPa, 122.90 MPa, and 121.60 MPa for Fe content of 0.12 wt. %, 0.16 wt. %, and 0.20 wt. % respectively. Similar trend was resulted with the UTS which the strength obtained were 274.39 MPa, 267.15 MPa, and 240.70 MPa for for Fe content of 0.12 %wt, 0.16 %wt, and 0.20 %wt respectively. The UTS for 0.20 %wt Fe concentration is below 245 MPa which the permissible value of as-cast aluminium according to JIS H 5202. It was found a significant decrease in UTS by app. 34 MPa (or equal to 12 %) due to the existing Fe in the structure 0.08 %wt higher from 0.12 %t to 0.20 %wt. This work concluded that having higher Fe concentration in the Al-Si alloy decreases the yield strength and UTS. This finding is in agreement with many previous works, e.g. Crepau [18] and Mbuya *et al*. [19].

Figure 5. Specimens after tensile test a) 0.12 %wt Fe, b) 0.16 %wt Fe, c) 0.20 %wt Fe

Table 2: Result of tensile test, hardness test and impact test

Fe concentration [%wt]	Yield point [Mpa]	UTS [Mpa]	Elongation [%]	Hardness [HRB]	Impact strength [J/cm^2]
0.12	128.33	274.39	7.44	24.06	15.47
0.16	122.90	267.15	5.16	26.24	2.91
0.20	121.61	240.70	4.57	27.66	2.59

The impact strength for Fe concentration of 0.12 %wt, 0.16 %wt and 0.20 wt. % are 15.47, 2.91, and 2.59 J/cm^2 respectively. The small increase in Fe concentration from 0.12 to 0.16 %wt shows a significant decrease in impact strength by app. 81%. Of all Fe concentration, only the impact strength at 0.12 %wt Fe can be higher than 5 J/cm^2 which is the minimum impact strength according to JIS H 5202. In agreement with the result of tensile test, samples after impact test confirm that Al alloy with the Fe concentration of 0.12 %wt shows the highest ductility (Figure 7). For Fe concentration of 0.12 %wt, the fracture surface shows brittle and ductile fracture region (Figure 8 and 9). Meanwhile, there is no ductile fracture zone for ferrous concentration 0.16%wt and 0.20 %wt, i.e. the brittle fracture zone becomes close to 100%. Should the brittle fracture region expand, material shows smaller elongation [20]. Based on the analysis of tensile and impact test results, it is concluded that Fe concentration up to 0.12 %wt still can be used as a maximum limit or as a reference value for car rims application.

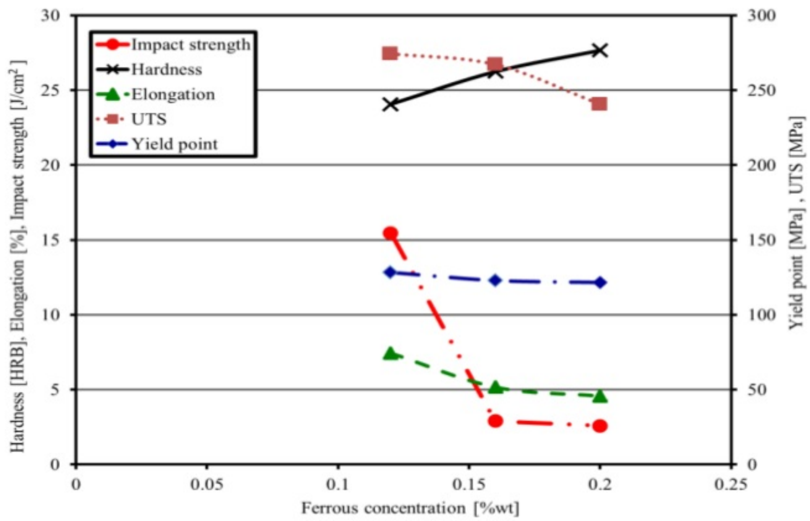

Figure 6. Hardness, tensile properties, and impact strength as function of Fe concentration

Figure 7. Side view of specimens after impact test a) 0.12 %wt Fe, b) 0.16 %wt Fe, c) 0.20 %wt Fe

Figure 8. Fracture surface of specimens after impact test a) 0.12 %wt Fe, b) 0.16 %wt Fe, c) 0.20 %wt Fe

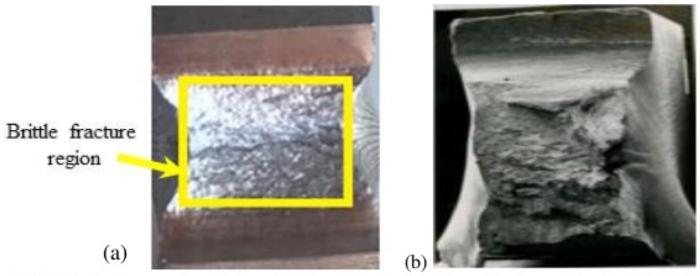

Figure 9. Brittle fracture region in the middle of fracture surface after impact test: a) 0.12 %wt Fe concentration in this work b) Sample studied by Chao *et al*. [20]

The hardness test shows a slightly increase of hardness as Fe concentration increases. The hardness for Fe concentration 0.12 %wt, 0.16 %wt and 0.20 %wt are 24.06 HRB, 26.24 HRB, and 27.66 HRB respectively. Increasing hardness is predicted due to the formation of hard Fe-rich intermetallic. In this present study, higher Fe concentration increases the alloy hardness but decreases the yield strength and UTS. This is a contradictive circumstance since in most cases materials hardness has a positive correlation with yield strength and ultimate tensile strength. Increasing casting defect with higher Fe concentration is suspected to be the reason for this contradictive circumstance. Insoluble phase particularly monoclinic crystal structure β (Al_5FeSi) increases with higher ferrous concentration (Figure 10). This negatively influences flowability and feeding characteristics since the β particles impede liquid flow [11]. Higher Fe concentration is reported to be responsible for high shrinkage porosity [21] as they tend to create more β (Al_5FeSi) particles which is suspected to act as nucleation site for porosity. In addition, higher Fe concentration also increases oxide formation which also impedes liquid flow [11].

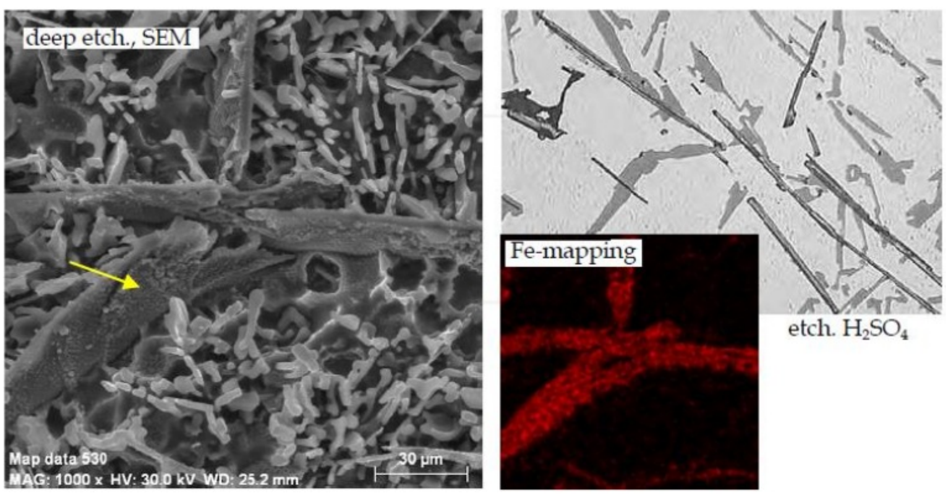

Figure 10. Morphology of Fe-phase Al_5FeSi [11]

4. CONCLUSION

Iron concentration in the A356.0 Al-alloy can result in a tremendous effect on mechanical properties of Al-alloy. The yield strength, elongation, ultimate tensile strength, and impact strength show a decrease with the higher Fe content in the alloy. The ultimate tensile strength significantly decreases by 34 MPa (equal to 12 %) when Fe concentration increases only by 0.08 %wt. Furthermore, the impact strength decreases from 15.47 to 2.91 J/cm^2 (equal to 81 %) when Fe concentration increases only by 0.04 %wt from 0.12 %wt to 0.16 %wt. In contrary, the hardness was found a slightly increase with the higher Fe content. This contradictive circumstance is predicted due to higher shrinkage porosity and lower fluidity with the present of higher Fe concentration. Based on the findings, A356.0 Al-alloy with maximum Fe content of 0.12 %wt is acceptable to produce as-cast car rims.

5. REFFERENCE

[1] JAPANESE STANDARD ASSOCIATION, "JIS 5202: Aluminium alloy casting", Japanese Standard Association, Tokyo, Mar. 2010.

[2] ZOLOTOREVSKY, V.S., BELOV, N.A., GLAZOFF, M.V., "Alloying elements and dopants: Phase diagrams", In: *Casting Aluminum Alloys*, chapter 1, Oxford, UK, Elsevier, 2007

[3] STADLER, F., ANTREKOWITSCH, H., FRAGNER, W., KAUFMANN, H., UGGOWITZER, P., "Effect of main alloying elements on strength of Al–Si foundry alloys at elevated temperatures", *International Journal of Cast Metals Research*, v. 25, n. 4., pp. 215-224, 2012.

[4] SJOELANDER, E., SEIFEDDINE, S., "The heat treatment of Al–Si–Cu–Mg casting alloys", *Journal of Materials Processing Technology*, v. 210, n. 10, pp. 1249-1259, 2010.

[5] ANZIP, A., SUHARIYANTO, S., "Peningkatan sifat mekanik paduan aluminium A356.2 dengan penambahan manganese (Mn) dan perlakuan panas T6", *Jurnal Teknik Mesin* v. 8, n. 2, pp. 64-68, 2006.

[6] ASGHAR, Z., REQUENA, G., KUBEL, F., "The role of Ni and Fe aluminades on the elevated temperature strength of an $AlSi_{12}$ alloy", *Materials Science and Engineering: A*, v. 527, n. 21-22, pp. 5691-5698, 2010.

[7] ZAMANI, M., *Al-Si cast alloys - microstructure and mechanical properties at ambient and elevated temperature*, Dissertation, Department of Materials and Manufacturing, School of Engineering, Jönköping University, Sweden, 2015.

[8] REQUENA, G., GARCES, G., RODRIGUEZ, M., PIRLING, T., CLOETENS, P., "3D architecture and load partition in eutectic Al-Si alloys", *Advanced Engineering Materials*, v. 11, n.12, pp. 1007-1014, 2009.

[9] TILLOVA, E., CHALUPOVA, M., and HURTAOVA, L., "Evolution of phases in a recycled Al-Si cast alloy during solution treatment", In: *Scanning Electron Microscope*, chapter 21, IntechOpen, London, UK, Mar. 2012

[10] KHALIFA, W., SAMUEL, F.H., GRUZLESKI, J.E., "Iron intermetallic phases in the Al corner of the Al-Si-Fe system", *Metallurgical Material Transactions A*, v. 34, n. 3, pp. 807-825, 2003.

[11] TAYLOR, J.A., "The effect of iron in Al-Si casting alloys", In: Proceedings of 35th Australian Foundry Institute National Conference, pp. 148-157, Adelaide, Nov. 2004.

[12] TAYLOR, J.A., "Iron-containing intermetallic phases in Al-Si based casting alloys". *Procedia Materials Science*, v. 1, pp. 19-33, Jun. 2012.

[13] ZIHALOVA, M., BOLIBRUCHOVA, D., "Influence of iron in $AlSi_{10}MgMn$ alloy", *Archives of Foundry Engineering*, v. 14, n. 4, pp. 109-112, 2014.

[14] Hadleighcasting, Aluminium technologies, https://ahead4-hadleigh-castings.s3.eu-west-2.amazonaws.com/content/9be6417437c62c701d950454bd4d7756.pdf, accessed on July 1, 2019.

[15] GASKELL, D. R., LAUGHLIN, D.E., "Introduction to the Thermodynamics of Materials, 6. ed., London, UK, CRC Press, 2017

[16] Japanese Standard Association, "JIS Z2241: Metallic materials-tensile testing-method of test at room temperature", Japanese Standard Association, Tokyo, Jun. 2012.

[17] Japanese Standard Association, "JIS Z2242: Method for Charpy pendulum impact test of metallic materials", Japanese Standard Association, Tokyo, Aug. 2018.

[18] CREPAU, P.N., "Effect of iron in Al-Si casting alloys: a critical review", *AFS Transactions*, v. 103, pp. 361-366, 1995.

[19] MBUYA, T.O., ODERA, B.O., NG'ANG'A, S.P., "Influence of iron on castability and properties of aluminium silicon alloys: literature review", *International Journal of Cast Metals Research*, v. 16, n. 5, pp. 451-465, 2003.

[20] CHAO, J., REMENTERIA, R., ARANDA, M., CAPDEVILA, C., GONZALES-CARRASCO, J.M., "Comparison of ductile-to-brittle transition behavior in two similar ferritic oxide dispersion strengthened alloys", *Materials*, v. 9, n. 8, pp. 637, 2006.

[21] TILLOVA, E., CHALUPOVA, M., "Fatigue failure of recycled $AlSi_9Cu_3$ cast alloy", *Acta Metallurgica Slovaca Conference*, v.1, n. 2, pp. 108–114, 2010.

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