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The effects of artificial-aging temperature on tensile strength, hardness, micro-structure, and fault morphology in AlSiMg

Andoko *, Yanuar, P. Puspitasari, T.B. Ariestoni
Mechanical Engineering Department, Engineering Faculty, State University of Malang, Semarang street No. 5, Malang, East Java, 65142, Indonesia
* Corresponding e-mail address: andoko.ft@um.ac.id
ORCID identifier: https://orcid.org/0000-0003-1923-2445 (A.)

ABSTRACT

Purpose: This research examined the effects of artificial-aging temperature and time on tensile strength, hardness, microstructure, and fault morphology in AlSiMg.

Design/methodology/approach: This research was conducted using aluminium alloy at 120°C, 150°C, and 180°C artificial-aging temperature and 6 hours holding time. The tensile test used ASTM B211-03 standard and hardness test adapted to ALCOA 6061 standard.

Findings: Tensile test results indicated the highest tenacity on aluminium alloy at a 150°C temperature that was 47.263% strain level. In addition to the strain level, this research also obtained the highest tensile strength level at 180°C that was 62.267 kgf/mm^2 and the highest hardness value that was 110 HV. The increase in tensile strength and hardness at 180°C was caused by the increase in Mg, Si, and Al. Based on the microstructure test, the highest tenacity was obtained at 150°C temperature as the result of closed and gathered Mg_2Si precipitates; while at 180°C temperature, the precipitates appeared to be more distributed, causing a rise in hardness value and tensile strength. AlSiMg tenacity also exhibited from the number of dimples compared to cleavages at 150°C temperature.

Research limitations/implications: The limitation that found in this research was conducted using AlSiMg aluminium Al6061 specimen with an artificial-aging treatment at 120°C, 150°C, and 180°C temperature for 6 hours and then compared to the raw material. AlSiMg tensile specimen was made according to ASTM E8-E8M standard.

Practical implications: This research can be applied in industrial manufacture process to find tensile strength, hardness, microstructure, and fault morphology of Al6061 alloy.

Originality/value: According to research result, can be understood that by conducting these experiments, Artificial-aging treatment temperature variations in AlSiMg aluminium alloy could increase hardness.

Keywords: Artificial-aging, Tensile streght, Hardness, Microstructure, Morphology, AlSiMg

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PROPERTIES

1. Introduction

Aluminium was discovered by Sir Humphrey Davy in 1809 as an element and reduced as a metallic substance by H.C. Oersted in 1825. It was then used industrially in 1886 [1]. Aluminium has a different nature compared to non-ferrous metals. Aluminium often used in the engineering area because of its unique and interesting natures, such as easy to work on, lightweight, good corrosion resistance, good electrical and thermal conductivity [2]. Aluminium has many uses, but it is often alloyed with other metals to achieve a harder, stronger, and rust-resistance alloy [3].

Aluminium mixed with iron, chromium, magnesium, silicon, manganese, copper, and zinc alloys have different effects [4]. One Alloy with a good characteristic of nature is AlSiMg aluminium alloy. Al-Si-Mg alloy generally has a high hardness response age [1,5]. This alloy could be heated and cut, weld, and has a good corrosion resistance [6]. This alloy can have T4 (natural aging) and T6 (artificial-aging) thermal treatment [7]. Before T6 or artificial-aging process was conducted, the material has to be given a solution heat treatment.

The first step of age hardening process is solution heat treatment or heat solvent treatment. Solution heat treatment of aluminium alloy is conducted in furnace at temperature of 550°C-560°C and holding it according to the type and size of work-piece [8]. In this step, the phases are dissolved into a solid solution. The purpose of solution heat treatment is to get a near homogenous solid solution [9]. Al-Si-Mg is treated with solution treatment at 540°C for 10 minutes and after a few hours will resulted in 90% ultimate tensile strength. Adding up to 30 minutes into solution treatment holding is enough for microstructure to get a 90% elongation value [10].

Quenching treatment is given after the solution heat treatment. Quenching is conducted by cooling the heated metal in a cooling medium [9]. Age hardening process is an aging process conducted to observe the change of material properties that happened during the aging process. One that is often used in aging processes is artificial-aging. Artificial-aging is an aging treatment by heating aluminium. Artificial-aging is conducted at a 100°C-200°C temperature and holding time one to 24 hours [8].

The previous researches stated that the highest concentration of mass deposition type Cu and Mg could be observed after 7 hours of the aging process at 170°C temperature [11]. Artificial-aging treatment with a temperature between 100°C-200°C would affect the degree of hardness because there would be changes in phase or structure during the process [12]. Mechanical properties test is conducted with breaking strength testers such as the tensile strength test and hardness test. The tensile test is conducted to get the tenacity value and UTS. Tensile testing is used to determine the stretch limit, tensile strength, extension, and broad reduction [13]. The specimen for tensile strength test is formed according to the ASTM E8-E8M standard. Hardness strength test is intended to get the hardness value from test object [14]. It indicates that the artificial-aging process could increase the aluminium alloy hardness.

Microstructure test is conducted to observe the structure form of metal material that previously experienced the solution heat treatment such as hardening, quenching, normalising, work-hardening, welding, etc. [15]. In the microstructural test, the material is rubbed using sandpaper and then etched. The purpose of etching is to make the metal structure or alloy characteristic clearer [16]. Fault morphology test is conducted to observe the resulting fracture forms after the specimen was given the break strength test. EDX or energy dispersive x-ray test is used to observe which element affects the mechanical nature of test object.

2. Methodology

The chemical composition (Tab. 1) shows the result of EDX test of elemental compositions showing that Al-Si alloys use Na-Bentonite combined with Portland cement and Ca-Bentonite mixed with Portland cement.That chemical composition of Al-Si alloy is used in this paper [1].

Table 1.
Chemical Composition of Al-Si alloy

	Al	Si	O	Mg	Fe
Na-Bentonite	74.95%	21.73%	1.57%	0.97%	0.78%
Ca-Bentonite	80.57%	15.82%	1.76%	0.92%	0.93%

This experimental research was conducted using AlSiMg aluminium alloy specimen with an artificial-aging treatment at 120°C, 150°C, and 180°C temperature for 6 hours and then compared to the raw material. AlSiMg tensile specimen was made according to ASTM E8-E8M standard.

This research was conducted by giving solution treatment at 530°C temperature with 30 minutes holding time in the heating furnace. Then, it was given quenching treatment to lower the specimen's temperature after solution treatment. The specimen, then, was heated again using artificial-aging at 120°C, 150°C, and 180°C temperature for 6 hours. After 6 hours, it was cooled down slowly in the furnace at room temperature. After artificial-aging, the specimen was given tensile strength and hardness test. Fracture from tensile test then was tested with a microstructural test using an optical lens tool and SEM fault morphology. After the microstructural test and fault morphology, the specimen was tested with SEM EDX to observe the element that affected mechanical nature changes.

3. Results and discussion

3.1. Tensile test results

In Figure 1, the strain values from aluminium alloy AlSiMg with artificial-aging on 120°C, 150°C, and 180°C temperature varieties exhibited up and down results as shown in the diagram. Compared with the raw material specimen that has 45.917% value, the highest value was on an aluminium alloy with 150°C temperature that was 47.263%. But at 120°C and 180°C temperature, the strain was decreased to 40.867% and 44.07%. In this case, AlSiMg with artificial-aging at 150°C temperature has the highest tenacity compared to other specimens. Tenacity measurement is a strain technique while breaking or reducing the section while breaking. The higher the strain, the higher the specimen tenacity is [17].

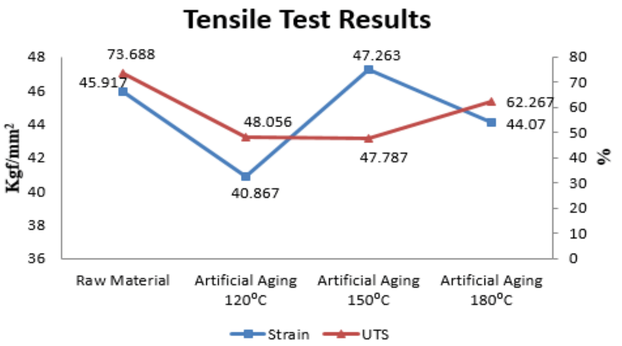

Fig. 1. Graphic of strain and UTS AlSiMg values with artificial-aging temperature variation

The ultimate tensile strength after artificial-aging temperature variation treatment resulted in the highest value that belonged to the raw material that was 73.688 kgf/mm^2. At 120°C temperature, the tensile strength decreased to 48.056 kgf/mm^2. At 150°C temperature, the tensile strength decreased to 47.787 kgf/mm^2. But, at 180°C, the tensile strength increased quite high, although still below the raw material, into 62.267 kgf/mm^2. The tensile strength value obtained after solution treatment and artificial-aging exhibited the value that was bigger than the ASTM B211-03 standard. The increase in strain value at 150°C was caused by Mg_2Si dissolving into Al matrix, and Si phase changed from plate shape to round shape that escalating the tenacity of the alloy during solution treatment. Whereas the increase in tensile strength occurred during artificial-aging, where the alloy on solution treatment gradually comes out and forms precipitates that could escalate the alloy strength.

The raw material value that was used as a comparison in tensile strength to other specimens showed that specimen with an artificial-aging treatment at 180°C had the highest tensile strength. The mechanical changes of nature towards AlSiMg alloy with artificial-aging indicated that aging temperature variation could increase the tensile strength in matrix Al – 7.14% Si – 1% Mg [14].

3.2. Hardness test results

Hardness test result obtained from AlSiMg aluminium alloy with artificial-aging temperature at 180°C has the highest hardness level that was 110.9HV but has a decreasing tenacity level of 44.07%. Artificial-aging with 150°C expressed the best result; this observed from the increased in hardness level compared to the raw material that was 99.45HV and higher tenacity level compared to artificial-aging at 120°C, 180°C, and raw material, that was 47.263%. According to ALCOA alloy 6061 standard, the standard for hardness test result is 95HB or 104HV [18]. With artificial-aging process at 180°C temperature for 6 hours was obtained 100.9HV in value, it exhibited an escalation in hardness value.

The hardness value of AlSiMg alloy was increasing because atoms precipitate Mg or Si in the matrix (Al). Mg or Si atoms after artificial-aging would be inclined to position themselves towards the solvent atom resulted in coherence [19]. The above explanation explained that artificial-aging could increase the hardness of aluminium alloy [14].

3.3. Fault morphology tensile test results

Figures 2-5 shows the result of fault morphology test on aluminium alloy AlSiMg specimen with artificial-aging at 120°C, 150°C, and 180°C, and raw material for 6 hours is a tenacious fault. This can be observed from the many amounts of dimples on fault morphology test result and little of cleavages [20]. Ductile fracture is shown with the number of dimples in microstructure result in the fault area. In addition to dimples, the fractured form also has cones and cups that proved it is a tenacious fault [21]. The form of tenacity on tensile test fracture can be observed by the cup and cone, which signed that the fault began in the middle then developed to the outside.

The highest ductile fault occurred in the aluminium alloy with artificial-aging at 150°C for 6 hours. Showed from Figure 4, the number of dimples dominated the fault morphology result. The previous statement corresponded with the tensile testing result that stated that 150°C temperature has a high tenacity indicated by strain value of 47.263%.

3.4. Microstructural test results

The microstructural test was conducted by rubbing the AlSiMg aluminium alloy specimen with sandpaper from

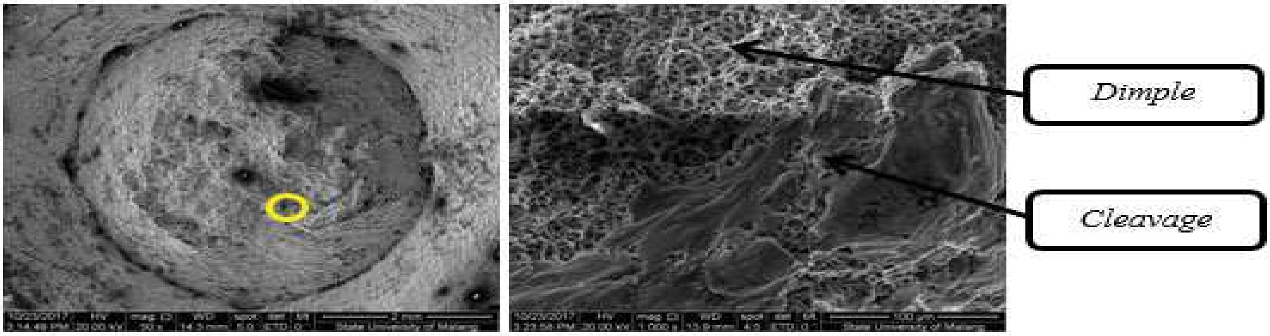

Fig. 2. Fault morphology tensile test result on raw material specimen

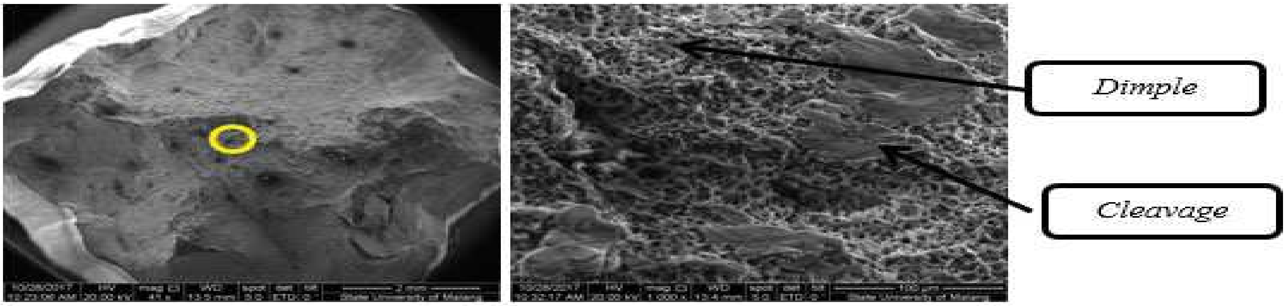

Fig. 3. Fault morphology tensile test result on AlSiMg alloy artificial-aging at 120°C temperature

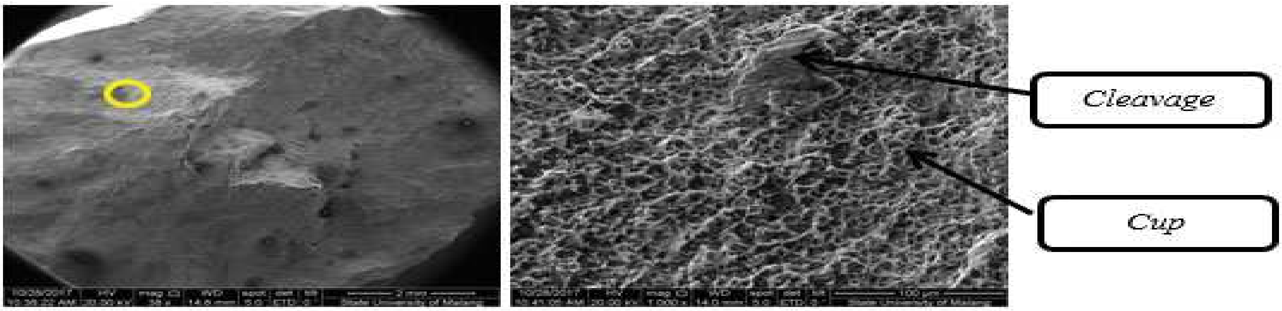

Fig 4. Fault morphology tensile test result on AlSiMg alloy artificial-aging at 150°C temperature

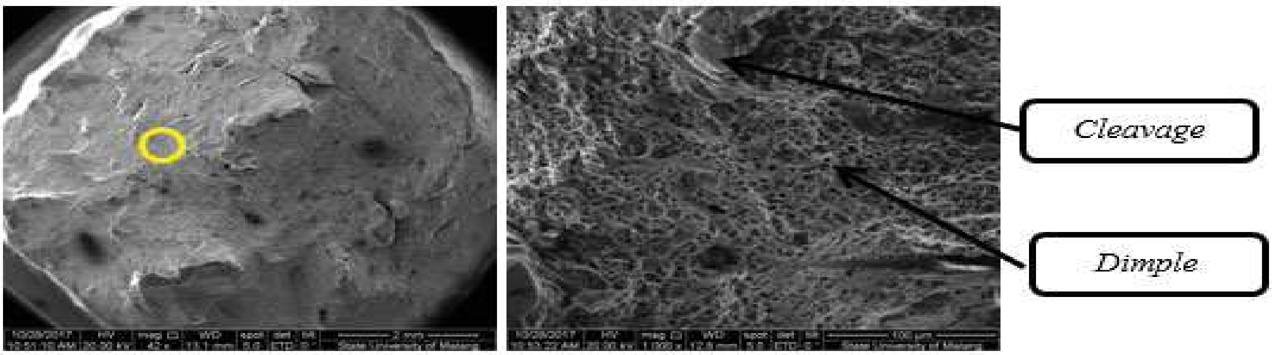

Fig. 5. Fault morphology tensile testing result on AlSiMg alloy artificial-aging at 180°C temperature

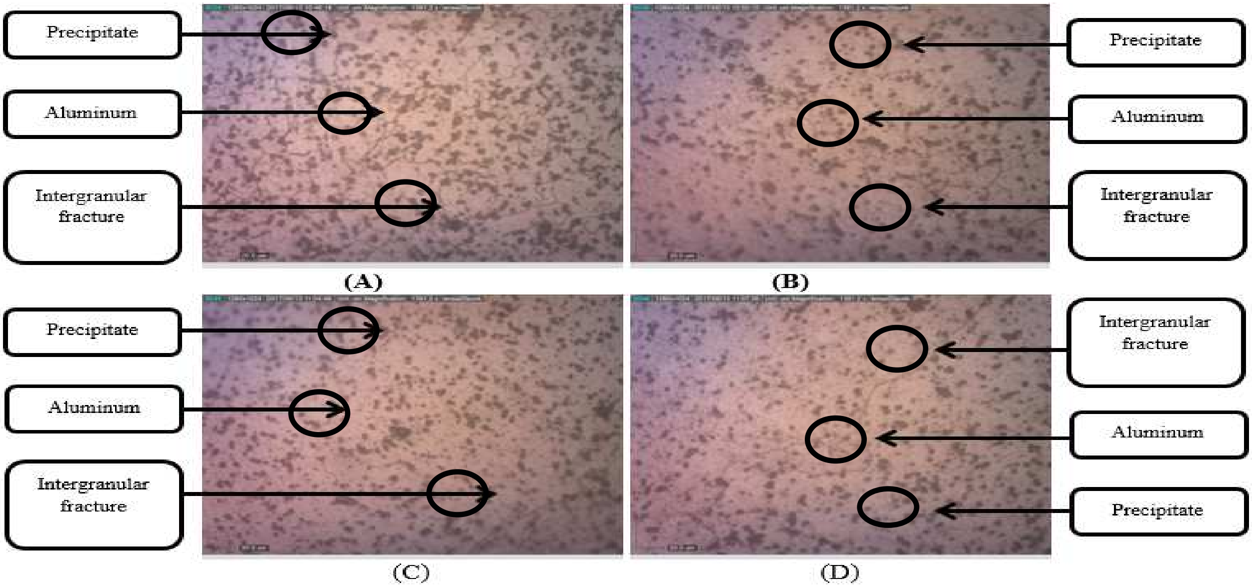

Fig. 6. Microstructure of AlSiMg in artificial-aging temperature (A) raw material, (B) 120°C, (C) 150°C, and (D) 180°C with 1391 magnitude

rough to a fine size. The sanding was focused on the last sanding using fine sandpaper so that the microstructural result was visible. After sanding, specimen then etched using allergen etching (HnO_3+Hf+H_2O) to help bring up the microstructure of AlSiMg aluminium alloy specimen of raw material and specimens that have been given artificial-aging treatment with 6 hours holding at various temperature.

The microstructural test results for AlSiMg aluminium alloy can be observed in the Figure 6.

Based on Figure 6, the precipitate (θ) can be observed in dark colors while matrix α – Al on bright colors. Precipitate in AlSiMg aluminum alloy is Mg_2Si as the previous research explained that Mg_2Si compound behaved as pure component and made a balance in a pseudo binary system with Al. As a practical alloy, it could be obtained as 5053, 6063, and 6061 alloy [15]. On microstructure test results, more precipitate means an increase in mechanical nature from the tested specimen; in accordance with the previous research that more formed precipitate equals to the rise of specimen's mechanic nature [22]. An even spread of precipitate could escalate the hardness and tensile strength [23].

In Figure 6, part (A) is a picture of the raw material microstructure that was used as a comparison for tensile strength value. In part B, precipitate still looks tenuous and uneven that caused a decreasing in tensile strength, tenacity, and hardness of artificial-aging at 120°C temperature. In part C, there are more precipitates but still close together that caused at 150°C tenacity and hardness increased more than raw material and existing standard, but the tensile strength is decreasing caused by uneven precipitate. In part D, there were more precipitates, but in part D, they spread evenly that caused the increase in hardness and tensile strength but decreasing in tenacity in AlSiMg aluminium alloy with an artificial-aging treatment at 180°C temperature.

3.5. EDX test results

EDX test was used to observe the elements both in the specimen with treatment and raw material. The average result of EDX on AlSiMg aluminium alloy can be seen in Figure 7.

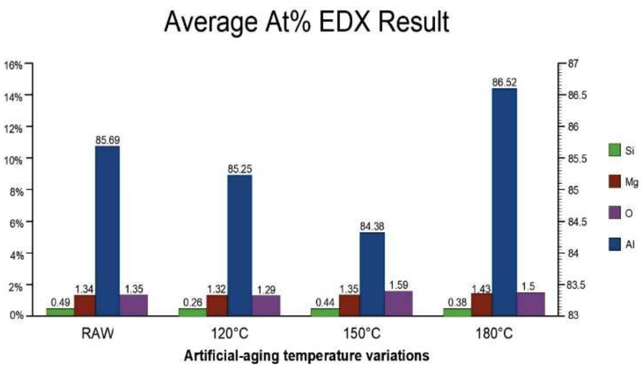

Fig. 7. Graphic of average Atomic Percent (At.%) AlSiMg with artificial-aging temperature variations

Figure 7 shows the EDX results for AlSiMg aluminium alloy specimen with an artificial-aging treatment at 120°C, 150°C, and 180°C. The raw material has Al – 85.69%, O – 1.35%, Mg – 1.34%, and Si – 0.49% values. These data used as references for other specimens. At 120°C, Al – 85.25%, O – 1.29%, Mg – 1.32%, and Si – 0.26% was obtained. At 120°C, Al, O, Mg, and Si experienced a decrease. At 150°C, Al – 84.38%, O – 1.59%, Mg – 1.35%, and Si – 0.44% was obtained. At this temperature, Al value decreased while other elements increased; but the increasingly Si value at this temperature was not as high as the raw material. At 180°C, Al – 86.52%, O – 1.5%, Mg – 1.43%, and Si 0.38%. At this temperature, Al and Mg got the highest value compared to other treatments. O level decreased compared to 150°C treatment, but still higher compared to other treatments. Meanwhile, Si value decreased, compared to 150°C temperature.

Standard used to the composition test, or EDX, is ASTM B211-03 standard that stated the standard for Si – 0.4-0.8%, Mg – 0.8-1.2%, and Al adjusts. From the EDX test result, it can be seen that the Mg value was not according to a standard that is 1.34% for raw material [24]. Mg and Si elements in the aluminium caused an increase in AlSiMg aluminium alloy yield strength. This occurrence is consistent with the previous research that stated that the additional number of magnesium and silicone would increase the yield strength [25]. The addition of silicone and magnesium compositions will form a Mg_2Si phase in aluminium matrix grain, where it would increase the strength [26]. Other than increasing the strength, Mg element also functioned to increase the hardness. In Figure 7, Mg element is the highest at artificial-aging at 180°C temperature with 1.43% value. It fits the hardness test where the highest hardness value occurred at AlSiMg aluminium alloy material with an artificial-aging treatment at 180°C that is 100.9HV. This also fits previous research that magnesium is an element that could increase strength and hardness on heat-treated Al-Si alloy [27]. The escalation of magnesium content and SiC booster could increase the strength of the composite piston and optimised the interface bond [28].

4. Conclusions

1. Artificial-aging treatment temperature variations in AlSiMg aluminium alloy could increase hardness.
2. Fault morphology test results show that the fault from the tensile test is a tenacious fault, as observed from the cone, cup, sheerlips, and dimple.
3. There are precipitates in AlSiMg aluminium alloy with artificial-aging treatment temperature variation that caused the specimen's change of mechanical nature. Si and Mg element on Al caused an escalation on the test specimen's hardness value.

References

[1] A.S. Masrikan, Effect of Natural Aging Heat Treatment on Hardness Level on Aluminum Alloy of Silicon Magnesium, Unpublished Thesis, Malang State University, Malang, 2015.

[2] E.P. DeGarmo, J.T. Black, R.A. Kohser, Materials and Processes in Manufacturing, Seventh Edition, Macmillan Publishing Company, New York, 1988.

[3] I. Anshari, Chemistry Study Reference 3, Erlangga, Jakarta, 1996.

[4] W. Suprapto, Gas Porosity in Duralumin Materials in Vacuum System Casting, 2011, Available at: lib.ui.ac.id/file?file=digital/20306755-D%201297-Porositas%20gas-full%20text.pdf, Accessed: February 4, 2017.

[5] A.M.A. Mohamed, F.H. Samuel, A review on the heat treatment of Al-Si-Cu/Mg casting alloys, in: F. Czerwinski (Ed.), Heat Treatment. Conventional and Novel Applications, IntechOpen, London, 2012, 55-72, DOI: http://dx.doi.org/10.5772/79832.

[6] G.K.C.J. Rogo, Suharno, Yadiono, Effect of Variations in Cast Temperature on Hardness and Micro Structures on the Results of Aluminum Remelting of Tromol Supra X with Metal Molds, 2013, Available at: http://jurnal.fkip.uns.ac.id/index.php/ptm/article/view/2657/1857, Accessed: February 28, 2017.

[7] T. Surdia, K. Chijiwa, Metal Casting Technique, Pradnya Paramita, Jakarta, 2013.

[8] A. Schonmetz, K. Gruber, Knowledge of Materials in Metal Working, Angkasa, Bandung, 1985.

[9] R.B.S. Majanasastra, Aging Heat Treatment Effect on Increased Hardness of Surface and Micro Structure of Honda Vario Motorcycle Piston Head, Islamic University of 45. Bekasi, 2015.

[10] D.L. Zhang, L.H. Zheng, D.H. StJohn, Effect of a short solution heat treatment time on microstructure and mechanical properties of modified Al-7wt.%Si-0.3 wt.%Mg alloy, Journal of Light Metals 2/1 (2002) 27-36, DOI: https://doi.org/10.1016/S1471-5317(02)00010-X.

[11] M. Kaczorowski, A. Krzynska, The influence of chemical composition on the properties and structure Al-Si-Cu-(Mg) alloys, Warsaw University of Technology Publishing House, Warsaw, 2007.

[12] F. Abdillah, Al-Si Alloy Heat Treatment in Piston Prototypes Based on Used Piston Materials, Thesis, Diponegoro University Semarang, 2010.

[13] T. Surdia, K. Chijiwa, Metal Casting Technique, Pradnya Paramita, Jakarta, 1982.

[14] J. Mulyanti, Effect of aging process temperature on material characteristics of stir casting Al-SiC metal composite, Journal of Technical Competence 2/2 (2011).

[15] S. Bagus, N. Media, UPN "Veteran", Jakarta Library, 2011, 135-140.
[16] D.I. Tsamroh, P. Puspitasari, Andoko, A.A. Permanasari, P.E. Setyawan, Optimization of multistage artificial aging parameters on Al-Cu alloy mechanical properties, Journal of Achievements in Materials and Manufacturing Engineering 87/2 (2018) 62-67, DOI: https://doi.org/10.5604/01.3001.0012.2828
[17] Asfarizal, Pengaruh temperatur yang ditinggikan terhadap kekuatan tarik baja karbon rendah, TeknikA 29/2 (2008) 53-59.
[18] ALCOA, Alloy 6061 understanding extruded aluminum alloys, Alcoa, 2002.
[19] Subowo, H. Subiyanto, Pengaruh Waktu Penahanan Artificial-aging Terhadap Sifat Mekanis dan Struktur Mikro Coran Paduan Al-7%Si, Indonesian Journal of Physics 13/3 (2002) 171-174.
[20] A.S. Kurniawan, Solichin, P. Puspitasari, Analisis Kekuatan Tarik Dan Struktur Mikro Pada Baja, Jurnal Teknik Mesin 22/2 (2014) 1-12.
[21] K.O. Pedersen, I. Westermann, T. Furu, T. Børvik, O.S. Hopperstad, Influence of microstructure on work-hardening and ductile fracture of aluminium alloys, Materials & Design 70 (2015) 31-44, DOI: https://doi.org/10.1016/j.matdes.2014.12.035
[22] R. Rochman, P. Hariyati, C. Purbo, Karakterisasi Sifat Mekanik dan Pembentukan Fasa presipitat pada Aluminium Alloy 2014-T_{81} Akibat Perlakuan Penuaan, Mekanika 8/2 (2010) 165-171.
[23] G.T Hahn, A.R. Rosenfield, Metallurgical factors affecting fracture toughness of aluminum alloys, Metallurgical Transactions A 6 (1975) 653-668, DOI: https://doi.org/10.1007/BF02672285
[24] ASTM, Standard Specification for Aluminum and Aluminum-Alloy Bar, Rod, and Wire [Metric], ASTM, 2015, 1-10.
[25] S.D. Chastain, Metal Casting: A Sand Casting Manual for the Small Foundry, Vol. II, Chastain Publishing, Jacksonville, 2004.
[26] B.C. Manik, Pengaruh Penambahan Unsur Silikon dan Magnesium Terhadap Sifat Mekanik dan Sifat Kelistrikan paduan Alu-minium Hasil Pengecoran, Skripsi, Institut Teknologi Sepuluh, Surabaya, 2017.
[27] Mugiono, Lagiyono, Rusnoto, Pengaruh Penambahan Mg Terhadap Sifat Kekerasan dan Kekuatan Impak Serta Struktur Mikro pada Paduan Al-Si Berbasis Material piston Bekas, Jurnal Teknik Mesin Juli (2013) 1-6.
[28] Radimin, A. Fuad, Studi Pengaruh Tekanan dan Komposisi Campuran pada Prototipe Piston Komposit dengan Penguat Silikon Karbida (SiC) Menggunakan Metode Squeeze Casting, Prosiding SNATIF Ke-1 Tahun 2014, 197-204.