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To cite this article: A Z Syahrial and M Al-Wafiy 2019 *IOP Conf. Ser.: Mater. Sci. Eng.* **547** 012013

Study of Strontium Effect on ADC12/Nano-Al_2O_3 Composite Characteristics with Al-Ti-B Grain Refiner Addition by Stir Casting Method

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Abstract. Cast iron are the common material used as brake-shoe component of the train, but this material has a high density of 7,25 g/cm^3, which tends to be heavy and causes more energy consumption. Aluminum composites can be used as alternative materials with less density. For improving the mechanical characteristic of the aluminum composite, grain modification can be done using strontium (Sr) addition. This research is intended to know the effect of variation of addition of Sr as a modifier on microstructure and mechanical properties of ADC12 composite material with reinforcement of 0,03 vf% nano-Al_2O_3 particles. Composite fabrication is done by stir casting method. The addition of Mg as wetting agent was 5 wt%, Al-5Ti-B as a grain refiner was 0.04 wt%, and Sr as modified grain with varying addition as much as 0.018; 0.021; 0.026; 0.028; and 0.037 wt%. To characterize the composite product, several testing is done, which is chemical composition characterization, metallographic observation, Scanning Electron Microscopy – Energy Dispersive Spectroscopy characterization, X-Ray Diffraction characterization, hardness testing, wear testing, tensile testing, and impact testing. The results of mentioned testing generally indicate an increase in mechanical properties of the material, due to the role of Sr in the morphological modification of silicon and quasi-binary Mg_2Si, secondary dendritic arm spacing size reduction, and wetting agents in the composite system. However, excess addition of Sr will increase the %porosity of the material.

Keywords: Aluminum composite, ADC12, nano-Al_2O_3 reinforcement particle, Strontium modifier

1. Introduction

In the development of the world of transportation, one that interesting is the fast-train industry. There are challenges faced by the fast-train industry, one of it is on the braking system. The braking system consists of many components, one of it is a brake shoe that works by direct contact with the fast train wheel. This component functions is to slow or stop the wheel rotation of the train when moving at a certain speed.
The basic materials used should have stable friction and wear resistance in variations of load, speed, temperature, and environment conditions, with high endurance. Material for fast-train brake shoe must also have good thermal stability to avoid distortion or cracking caused by

thermal stress due to friction. In addition, the weight of components and manufacturing processes is also an important factor to be considered in designing fast train brake shoe.
The material commonly used as a brake shoe is cast iron. However, cast iron has a high density of 7.25 g/cm^3, which tends to be heavy and causes more energy consumption. Resilience of this type of material is also low, resulting in high cost for routine maintenance, especially for brake shoe replacement [1].
Currently, the development of aluminum-based components in world of transportations is being done significantly, which can also be adapted by the fast-train industry. Aluminum alloys can be used as a base matrix with the addition of a ceramic reinforcement forming a composite system, which demonstrates promising capabilities in the needs of this type of application (brake shoe) [2]. This material has a lower density (2.7 g/cm^3) and better thermal conductivity compared to conventional materials. Bayuseno and Nugroho [3], revealed that the brake shoe with composite materials will have a lifetime that can be increased up to three times compared to conventional materials. The weight reduction in the braking system can reach 50% - 60%. Moreover, this type of material demonstrates better performance potential under heavier application conditions [4].
Alloying elements can also provide mechanical properties improvement, which are used in this study is Strontium (Sr). Sr addition was carried out on the casting of Al-Si alloys with the aim of changing the crystalline morphology of silicon from acircular flakes to fibrous rod-like form, which giving the positive effect of mechanical properties of the aluminum product [11].
The aim of this study is, to investigate experimentally the effect of variations of addition of Sr as alloying element on microstructure and mechanical properties of aluminum composite material with reinforcement of ceramic particles.

2. Materials and Methods

2.1. Materials

In this work, Aluminum ADC12, which obtained from PT Ogindo Prakarsatama, was used as the matrix, with reinforcement of 0,03 vf% nano-Al_2O_3 particles, which obtained from US Research Nanomaterials, Inc. Some addition was also made, there were 5 wt% of Magnesium as wetting agent, 0.04 wt% of Al-5Ti-B as a grain refiner, and Strontium as grain modifier with varying addition as much as 0.018; 0.021; 0.026; 0.028; and 0.037 wt%. These alloying substances were obtained from PT. Makmur Meta Graha Dinamika.

Table 1. Chemical Composition of Aluminum ADC12

Si (%)	**Cu (%)**	**Mg (%)**	**Mn (%)**	**Fe (%)**	**Ni (%)**	**Zn (%)**	**Sn (%)**	**Others (%)**	**Al (%)**
9,5 – 11,5	2,0 – 3,0	max 0,1	max 0,5	max 1,3	max 0,3	max 3,0	max 0,15	max 0,5	bal.

2.2. Experimental Methods

ADC12 which already weighed inserted into the tilting furnace, then raised to 700^{o}C incremently until completely melted. In parallel, nano-Al_2O_3 powder were vibrated as the preparation before it was added to the molten ADC12. After that, insert Mg, Al-Sr, and Al-5Ti-B into the melt of ADC12, then stir for 2 minutes to get homogenous mixture. Degassing should be done to remove trapped gases inside the molten metal. Insert Al_2O_3 powder that has been preheated, slowly while stirring for 2 minutes. Then, pour melt into the mold which has been preheated before. Open the mold after the composite solidified for later removal from the mold.

2.3. Characterization

To characterize the composite product, several testing was done, which was chemical composition characterization using Optical Emission Spectroscopy, metallographic observation based on ASTM E3-11 using Zeiss Primotech Microscope, Scanning Electron Microscopy – Energy Dispersive Spectroscopy (SEM-EDS) characterization, X-Ray Diffraction (XRD) characterization which analyzed using PANanalytical HighScore Plus, hardness testing based on ASTM E18-11 (Rockwell B method), wear testing using Ogoshi Machine, tensile testing based on ASTM B557M-02A using Gotech AL-7000 LA 10, and impact testing based on ASTM E23-01 using GoTech Testing Machine. There was also a feasibility study of composite material as substitution of cast iron material in its application as component of brake shoe of train.

3. Results and Discussion

3.1. Chemical Composition

The ADC12 material used identified that comply with the compositional standards of aluminum alloys ADC12, so it is appropriate to use as a matrix in composite manufacturing processes. We observed a significant increase in magnesium value from 0.221 wt% to more than 5 wt%. This is due to the addition of magnesium of 5 wt% as a non-volatile wetting agent, resulting in a major solidification reaction no longer Al-Si-Cu but Al-Si-Mg.
The difference in strontium content obtained is at a significant value, but the excess strontium element content in the composite is still tolerable, which is below the 0.12 wt%, so it does not form an intermetallic compound which is not desired [5].

Table 2. Chemical compotition of ADC12 as a matrix and Composite Materials

Elements	**Content (wt%)**					
	ADC12	**Composite 1**	**Composite 2**	**Composite 3**	**Composite 4**	**Composite 5**
Al	84,80	79,700	79,800	79,200	78,633	79,500
Si	10,50	11,130	10,587	10,453	11,007	10,547
Cu	2,330	1,800	1,800	1,970	1,980	1,800
Mg	0,221	5,320	5,700	6,320	6,317	6,267
Fe	0,864	0,616	0,622	0,534	0,557	0,551
Sr		0,018	0,021	0,026	0,028	0,037
Ti	0,046	0,092	0,094	0,081	0,095	0,093
B		0,003	0,003	0,003	0,003	0,003
Cr	0,039	0,050	0,048	0,037	0,043	0,032
Mn	0,223	0,122	0,115	0,115	0,116	0,111
Bi		0,006	0,007	0,006	0,005	0,007
Ni	0,076	0,039	0,036	0,027	0,032	0,028
Zn	0,637	0,599	0,619	0,555	0,613	0,568
Sn	0,080	0,008	0,013	0,005	0,006	0,007
others	0,144	0,496	0,536	0,668	0,671	0,450

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Copper contained in the ADC12 material is at a value of 1.80 - 2.00 wt%. In such content, $CuAl_2$ compound formed, which will increase the strength of the material [6]. Fe content derived from ADC12 base material is categorized high enough and can form an intermetallic phase of β-Al_5FeSi with a needle-shape morphology that can decrease the mechanical properties of the material [7].

3.2. SEM-EDS and XRD Examination

Figure 1 (a) SEM and (b) XRD observation result of composite material

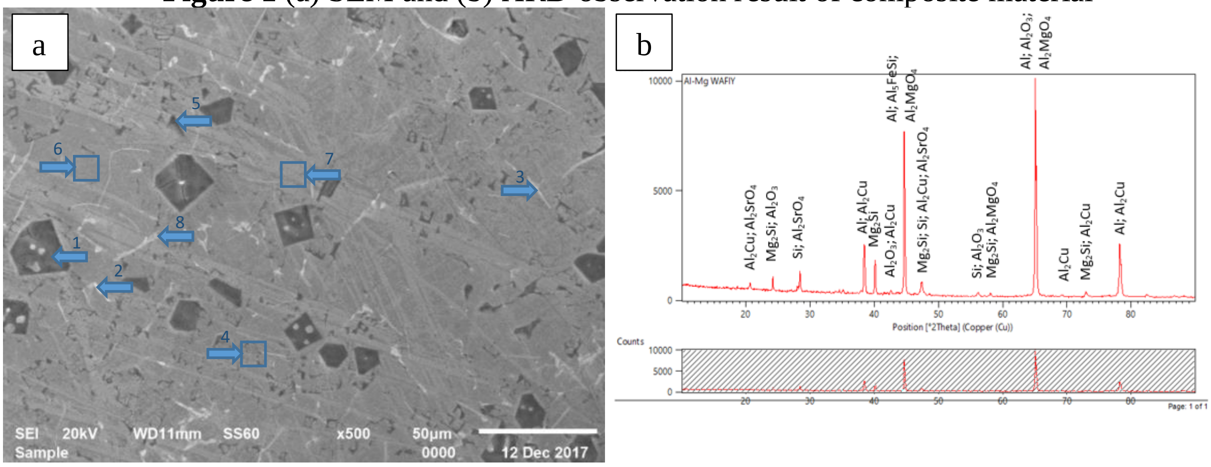

Table 3. Chemical composition of phase based on SEM-EDS examination

Number	Content (wt%)								Possible Phase
	C	O	Mg	Al	Si	Ti	Fe	Cu	
1	11,66	22,21	41,79	0,21	23,98	0,02	0,05	0,08	Mg_2Si
2	25,39	0,57	2,73	57,34	2,84	0,13	0,16	10,84	Al_2Cu
3	28,58	1,28	0,51	57,99	7,07	0,03	2,69	1,85	β-Al_5FeSi
4	8,47	2,94	4,87	80,15	2,92	0,00	0,00	0,64	Al+Mg_2Si
5	19,60	2,50	12,12	60,59	4,61	0,00	0,00	0,57	Al+Mg_2Si
6	7,97	0,70	0,73	79,65	10,22	0,01	0,09	0,64	Al+Si
7	8,89	0,81	1,36	80,11	7,73	0,14	0,29	0,67	Al+Si
8	21,39	0,84	0,16	73,71	0,91	0,02	0,08	2,90	Al_2Cu

Based on SEM-EDS observation, and also supported by the result of XRD examination, it can be seen that the presence of Mg_2Si primary phase in the form of blocky and black, which shown by arrow number 1. Mg_2Si is an intermetallic phase with low density, high melting point, good hardness characteristic and elastic modulus, also low coefficient thermal expansion. Therefore, it is clear that Mg_2Si provides excellent mechanical characteristics in composite materials [8]. Quasi-binary phase Al + Mg_2Si is indicated by arrows number 4 and 5. Al + Mg_2Si can be observed with in chinese-script morphology.

Fe content that is high enough in this study formed the intermetallic phase β-(Al_5FeSi) which has a needle-like morphology and gray as shown in arrow numbered 3. The presence of Al_2Cu intermetallic phase can also be known from the arrow number 2. Al_2Cu intermetallic phase will increase the value of UTS of the composite material [6].

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In point 8 it appears that Al Cu is in a needle-like phase, based on research conducted by S. G. Irizalp and N. Saklakoglu [9], this is an Al_2Cu phase attached at the β-Al_5FeSi intermetallic phase which has needle-like form.
Aluminum as the main matrix can be observed by arrows number 6 and 7. The presence of silicon at high enough value in these points indicates that there is the existence of silicon eutectic crystals.
The presence of other elements at each SEM-EDS identification point was also observed, among them were oxygen (O) and carbon (C). The oxygen in this study is contained from the addition of Al_2O_3 reinforcing particles. While the high carbon content was identified as a result of refractory wear used in the composite fabrication process, the refractories used were SiC types.

3.3. Microstructure

Figure 2 Microstructure of Composite Materials; (1) α-Aluminum, (2) Silicon, (3) primary Mg_2Si, (4) quasi-binary Mg_2Si, and (5) β-Al_5FeSi

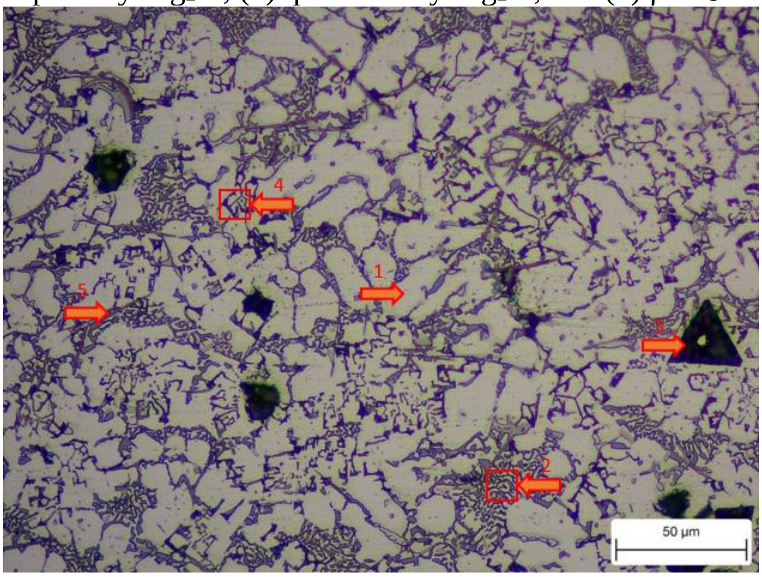
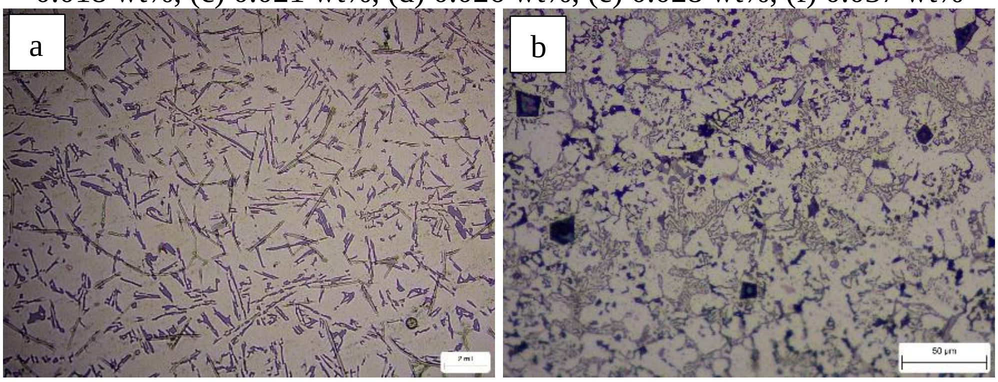
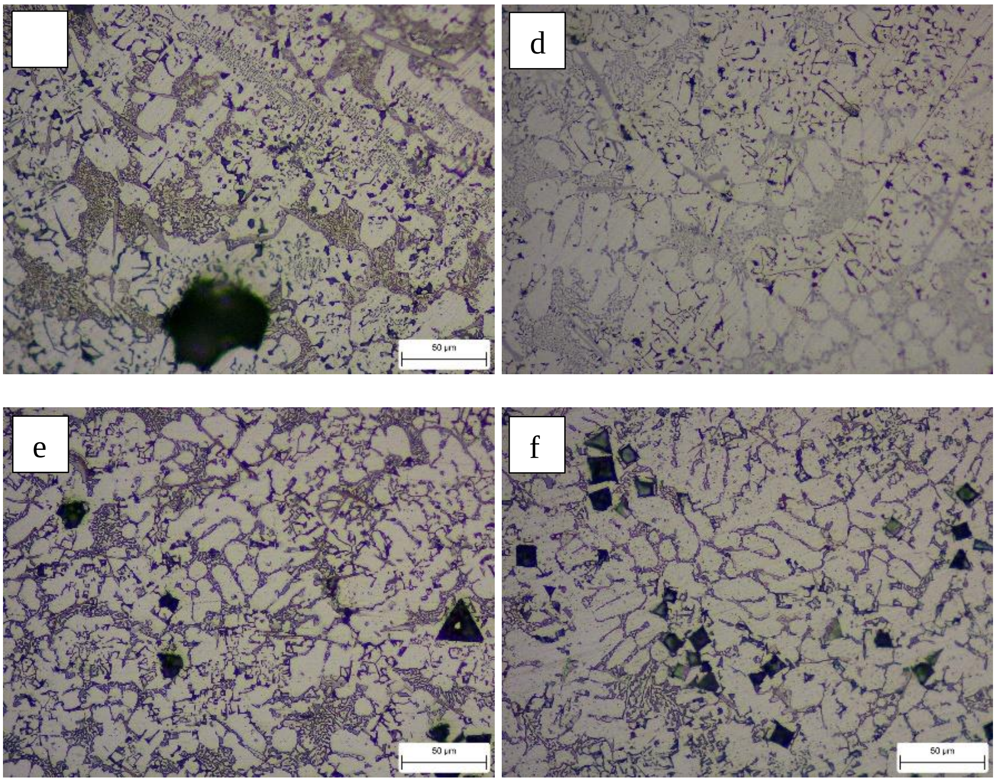


Figure 3. Microstructures of (a) ADC12 and Composite Materials with Additions of Sr (b) 0.018 wt%, (c) 0.021 wt%, (d) 0.026 wt%, (e) 0.028 wt%, (f) 0.037 wt%





The effect of Sr addition is observed on the morphology of silicon crystals from initially acircular flakes shape modified into fibrous rod-like forms. The distance between the crystals of silicon will also be closer.

Strontium can also modify the quasi-binary Mg_2Si phase chinese-script morphology. As is known, chinese-script morphology can reduce the mechanical strength of composite materials due to the easy crack nucleation along the interface between quasi-binary Mg2Si phase with α-Aluminum. With the addition of Strontium, the Mg_2Si morphology becomes very smooth, and the chinese-script form changed into more rounded or irregular polygons.

Strontium also affects secondary dendritic arm spacing (SDAS) values of α-Aluminum grains. This is due to the addition of strontium made α-Aluminum to be more columnar, due to the properties of strontium that can initiate the growth of columnar dendrites in Al-Si alloys, thereby reducing the size of SDAS [10].

3.4. Mechanical Properties

Figure 4. Effects of SR addition on the (a) hardness, (b) wear rate, (c) ultimate tensile strength, (d) elongation, and (e) impact toughness characteristics of composite materials

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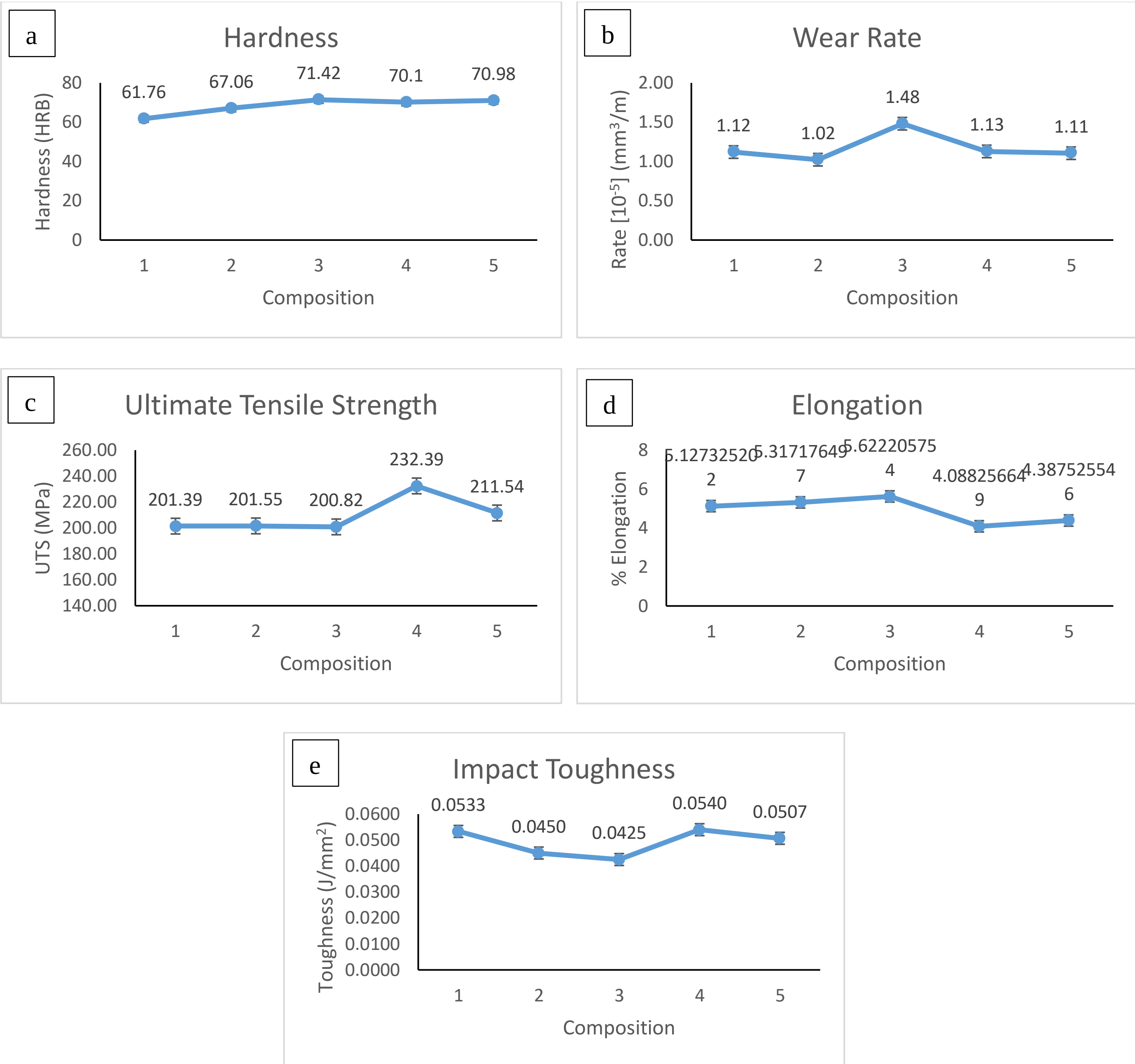

Hardness of composite material generally showed better characteristic with increasing amount of strontium added, with optimum value of 71,42 HRB in addition of Sr as much as 0,026 wt%, due to effect of modification of silicon crystals morphology and chinese-script Mg_2Si, and reduction of size SDAS [11].

The wear resistance of the composite material generally shows good characteristic with the addition of strontium, with the smallest wear rate value being 1.0223 x 10-5 mm2 in addition of strontium of 0.021 wt%, due to modification of the silicon crystals as the load-bearing phase during wear loading [12].

Tensile strength, elongation, and impact properties of composite material showed better characteristic with strontium addition, due to the effect of modification of silicon crystals morphology and chinese-script Mg_2Si [13] and the role of strontium as a wetting agent [14].

Looking at the mechanical characteristics of the composite, this material is very potential and suitable for use as a substitution material of cast iron in its application as a train brake shoe in the future [15].

4. Conclusion

- Strontium as grain modifier can modify silicon crystal morphology from acircular flakes to fibrous rod-like form, quasi-binary Mg_2Si quasi-binary chinese-script morphology becomes more refined and uniformly distributed, and forms α-aluminum to be more columnar.
- In general, there is an increase in the mechanical characteristics of the material as the amount of Strontium is added.
- The ADC12 / nano-Al_2O_3 composite material is considered feasible as a subtitution material for cast iron in the future application as a component of the train brake shoe, due to it's generally superior mechanical characteristics.

5. Acknowledgements

Authors would like to express their gratitude for financial support from the Directorate of Research and Community Services (DRPM), Universitas Indonesia, through International Publications Index for Final Year Students Projects Grant (PITTA) 2018 with contract number: 2378/UN2/R3.1/HKP.05.00/2018

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