Effect of Barium (Ba) Addition on Dry Turning of a Commercial Al-20Mg2Si-2Cu Metal Matrix Composite

Effect of Barium (Ba) Addition on Dry Turning of a Commercial Al-20Mg_2Si-2Cu Metal Matrix Composite

Abbas Razavykia[1], Hamidreza Ghandvar[2], Mohd Hasbullah Idris[3]
[1]Department of Mechanical and Aerospace Engineerin, Politecnico di Torino, 10129 Torino, Italy
[2,3]Department of Materials, Manufacturing and Industrial Engineering, Faculty of Mechanical Engineering, Universiti Teknologi Malaysia (UTM), 81310 Johor Bahru, Malaysia

Abstract- The principle aim of this study was to observe the effect of machining parameters as well as the separate additions of 0.2wt% barium (Ba) on the machinability of Al-20%Mg_2Si in situ metal matrix composite. Microstructure alteration, surface roughness and cutting temperature were taken into account as indices to examine the effect of modifier and machinability during dry turning. The results showed that addition of Ba as modifier reagent results in lower cutting temperature and better surface roughness due to the formation of Ba compound and modification of morphology of Mg2Si reinforcement particle.
Keywords – Al-Mg_2Si composite, Barium, Machinability, Cutting temperature, Surface roughness

I. INTRODUCTION

Recently Al-Mg_2Si composite with internally in situ synthesized reinforcement particles has gained significant attention for application in automotive and aerospace industries due to low density and appropriate mechanical and tribological properties [1]. Furthermore, in situ fabrication of the composite during casting has more merit such as thermodynamic stability of particles, more homogeneous distribution of the dispersed phase particles and strong interface between reinforcement and matrix compared to ex situ counterpart [2]. However during solidification of Al-Mg_2Si composite, formation of coarse dendritic morphology of primary Mg_2Si and Chinese script eutectic Mg_2Si particles decrease the mechanical properties and machinability of the cast composite; because the big size and coarse primary Mg_2Si particles act as an abrasive and result in high rate of tool wear and short tool life thereby increasing the overall cost of production. Therefore, it is crucial to modify the structure of Mg_2Si particles in order to improve mechanical and machinability properties. Substantial studies have been carried out during last years to refine and modify the microstructure of Al-Mg_2Si composite through casting with addition of alloying elements into the melt such as bismuth (Bi) [3], strontium (Sr) [4], lithium (Li) [5], phosphorous (P) [6], yttrium (Y) [7], manganese (Mn) [8], antimony (Sb) [9], mischmetal [10], and Gadolinium (Gd) [11]. For example, Razavykia, et al [12] reported that with addition of 0.4 wt. % Bi as modifier to Al-20%Mg_2Si, Bi compound formed which modified the morphology of Mg_2Si reinforcement particle and as a result better surface roughness and lower cutting force were obtained during machining. Similarly, Yosuf et al [13] found that addition of 0.4 wt. % Bi, 0.8 wt. % Sb, and 0.01 wt. % Sr to Al-Mg_2Si composite significantly modify the morphology of Mg_2Si which influenced the machining of cast composite by increasing in cutting force and reducing the surface roughness. It has also been shown that the presence of Ba has a refinement effect on the size and morphology of eutectic silicon in Al-Si alloys [14] and Mg_2Si reinforcement particles in Mg-Zn-Si alloy [15]. To best of our knowledge, most of the previous studies focused on microstructure and mechanical properties of Al-Mg_2Si composite and few researches have been conducted about machinability investigation of Al-Mg_2Si composite especially with Ba addition. Therefore, the aim of present study is to determine the effect of each variable and their reciprocal interaction on the machinability characteristic of Al-Mg_2Si composite to provide necessary information needed for machining of the cast composite.

II. EXPERIMENTAL PROCEDURE

In order to fabricate Al-20%Mg_2Si composite ingot, commercial Al-11.7Si-2Cu alloy, pure aluminum, and pure magnesium were used, in which the chemical composition is given in Table 1. The composite ingot was cut into small pieces and melted in a 5kg SiC crucible using induction furnace with a melt temperature of 750± 5 ºC. After degassing of molten metal with C_2Cl_6 tablets, 0.2 wt. % of pure barium (>99.0 wt. %) was introduced into the molten alloy. After dissolution and homogenization for around 5 min the melt was stirred, skimmed and then carefully poured at the temperature of 730 ± 5 ºC into a mild steel mold to fabricate the cylindrical work-piece. The process was repeated to produce the composite work-piece without Ba addition. In order to reveal the microstructure of the samples, metallography specimens were cut from the work-pieces and prepared by standard grinding and polishing with colloidal silica (5μm). The microstructure was examined with a Nikon optical microscope (MIDROPHOT-FXL) and scanning electron microscopy (Philips XL40) coupled with energy dispersive spectroscopy (EDS) facility. The experimental machinability trials were performed on Al–20%Mg_2Si (Non-modified) and Al–20%Mg_2Si–0.2%Bi (Modified). The specimens were rough turned to obtain uniform bar with dimensions of 93 mm in diameter and 315 mm in length and then mounted on CNC lathe machine (Alpha 1350S, Harrison, UK, 8.3 kW power drive and maximum 6000 rpm spindle speed). A standard Kennametal tool holder (SVJBR-2020K11) has been applied to hold the inserts during turning. Dry orthogonal turning was performed at different combinations of cutting speeds (100, 200, and 300 m/min), feed rates (0.1, 0.2, and 0.3 mm/rev) and constant depth of cut of 0.5 mm for all tests. Surface roughness and cutting zone temperature were considered as response factors. In order to reduce the effects of vibration several precautionary steps were considered. Firstly, the cutting tool was chosen with positive rake angle and a smaller nose radius than depth of cut (0.2 mm < 0.5 mm) to reduce cutting forces; and secondly the insert was selected with a chip breaker in order to reduce friction and contact between the chip and rake face. Therefore, Kennametal coated carbide (K10U) insert with 35° rhomboid geometry, nose radius of 0.2 mm and, 5° relief angle has been applied to conduct investigation trials. The surface roughness was tested using surface roughness tester (CS5000, Mitutoyo, Japan). FLIR thermal camera E50 and its software FLIR Tools Software have been used to record and analyze the cutting zone temperature as shown in Figure 1.

Table -1 Chemical composition of the cast Al–20Mg_2Si primary ingot (wt. %)

Element	wt. %	Element	wt. %
Mg	12.80	Ni	0.01
Si	7.50	Ti	0.01
Fe	0.64	Cu	2.03
V	0.02	Mn	0.01
Cr	0.01	Al	Bal.

Figure 1. FLIR thermal camera mounted on turning machine tool post DWT Decomposition model

III. EXPERIMENT AND RESULT

3.1 Microstructure analysis

Figure 2 (a-d) shows the SEM micrographs of Al–20Mg_2Si work-piece with and without barium addition in low and high magnifications. As it can be seen in Figure 2a, b the primary Mg_2Si particles are exist in coarse polyhedral shape with hollow in the center which is typical morphology of non-modified primary Mg_2Si. The micrographs of Al–20Mg_2Si work-piece containing 0.2 wt. % Ba are shown in Figure 2c, d. From the microstructure observation it is clear that addition of Ba into the composite altered the size and morphology of primary Mg_2Si particles in which the particle size is decreased and the morphology is changed to cubic shape after treating with Ba addition compared to unmodified composite. In addition, the assessment of quantitative metallography features of Mg_2Si particle including the mean size, mean aspect ratio and mean density was performed by using i- Solution image analyzer. Addition of Ba leads to significantly alteration in aforementioned Mg_2Si features. The obtained results demonstrated that in unmodified Mg_2Si particle, the mean size is about 40μm, the mean aspect ratio is 1.30 and the mean density is 1589 particle/mm^2. However, after modification with Ba addition, the mean size and aspect ratio decreased to 30μm and 1.19 respectively, and the mean density increased to 2383 particle/mm^2. This implies that the mean size and aspect ratio decreased by 25% and 8% respectively and the mean density increased 33%. The features values clearly indicate modification of Ba addition on primary Mg_2Si particles in Al-Mg_2Si composite.

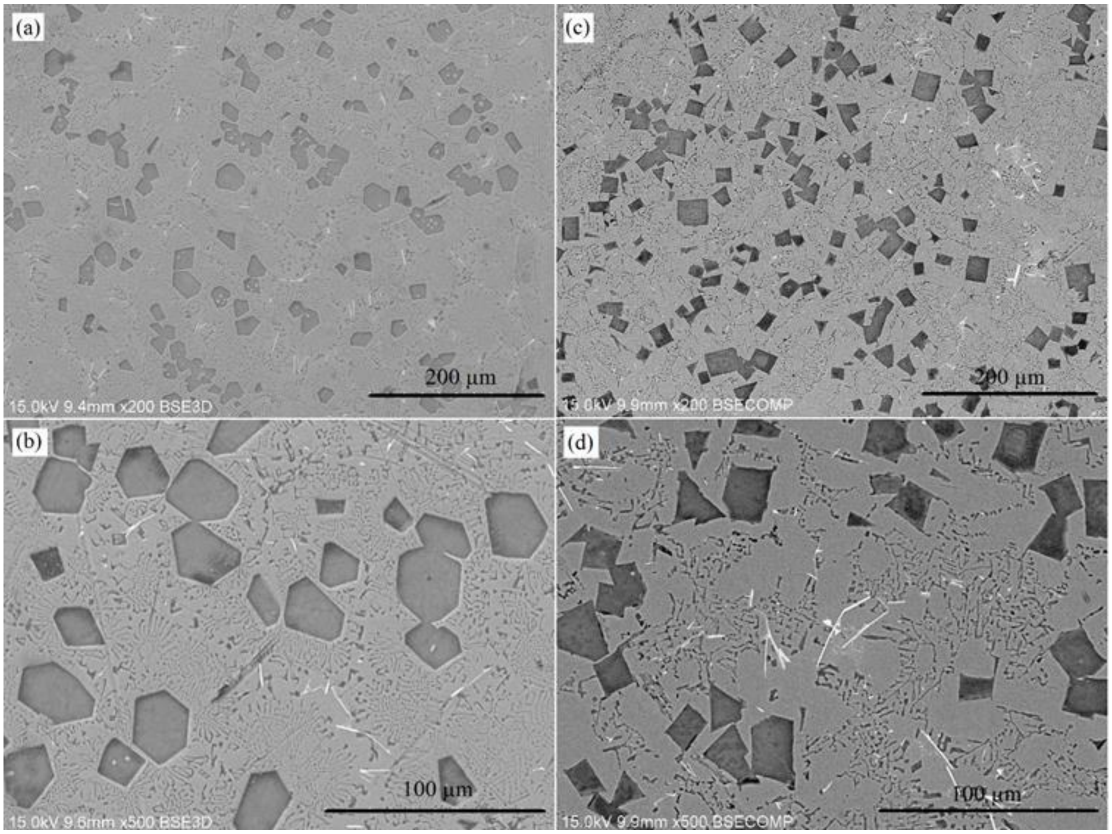

Figure 2. SEM micrographs of Al–20Mg_2Si composite (a and b) without and (c and d) with Ba addition

Figure 3 depicts the back scattered electron (BSE) micrograph of the work-piece modified with Ba. A white particle was observed on the microstructure near to the Mg_2Si particle. The corresponding energy dispersive spectroscopy (EDS) indicated that this particle is a Ba-compound containing Al, Si and Ba and based on atomic percentage it is $BaAl_2Si_2$ intermetallic compound. Therefore, the possible modification mechanism of primary Mg_2Si by Ba addition can be related to heterogeneous nucleation, restricted growth mechanism due to presence of $BaAl_2Si_2$ phase close to Mg_2Si particle and poisoning effect by changing the surface energy of primary Mg_2Si which leads to hinder growth in certain directions.

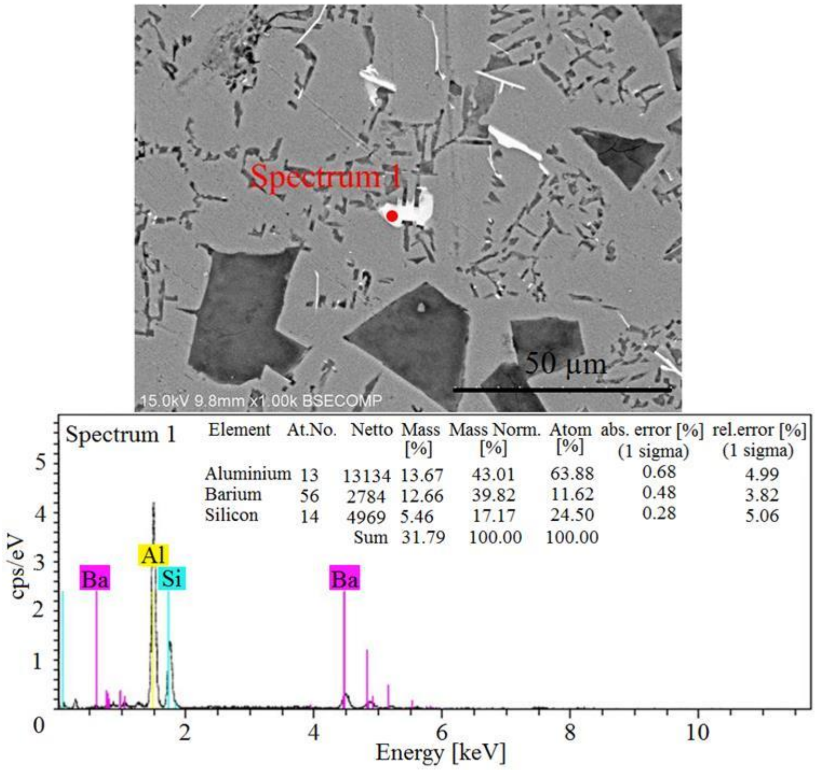

Figure 3. BSE image and corresponding EDS spectra of Ba particle (white area)

3.2 Cutting Temperature

Table 2 summarizes recorded cutting zone temperature for both work-pieces, Ba modified and non-modified for all machining conditions. At the given cutting speed, as feed rate increases the cutting zone temperature increases, due to higher load imposed on tool tip and larger material flow on the rake face of the tool and consequently larger friction force [16]. Figure 4 (a) presents the dependency of cutting zone temperature on feed rate at the cutting speed of 100 m/min. The higher cutting speed the lower temperature at given feed rate as shown by Figure 4 (b) which shows the variation of temperature with respect to cutting speed at feed rate of 0.1 (mm/rev). Due to higher particle density in modified specimen, the tendency to form built-up edge (BUE) is reduced and the geometry of cutting edge does not change too much especially the tool nose radius. Higher density of the particles makes the chips more brittle and consequently lower continued contact between chips and rake face of the tool. Figure. 5 shows the cutting temperature variation during the mashing of non-modified specimen at the cutting speed of 100 m/min and feed rate of 0.1 mm/rev. Lower mean size and aspect ratio of the particles in modified specimen affects the impact load between particles and the tool tip, smaller particles provide lower interface by the matrix and reduce the load to require the plastic deformation and material flow behavior between the particles [12, 13].

Table -2 Cutting zone temperature for modified and non-modified specimens

No.	Cutting speed (m/min)	Feed rate (mm/rev)	Average Cutting zone temperature (non-modified, °C)	Average Cutting zone temperature (modified, °C)
1	100	0.1	66.81	63.3
2	200	0.1	58.43	56.3
3	300	0.1	54.10	52.14
4	100	0.2	81.12	80.12
5	200	0.2	62.18	75.2
6	300	0.2	65	72.6
7	100	0.3	90.49	86.21
8	200	0.3	63.92	82.4
9	300	0.3	67.6	70.82

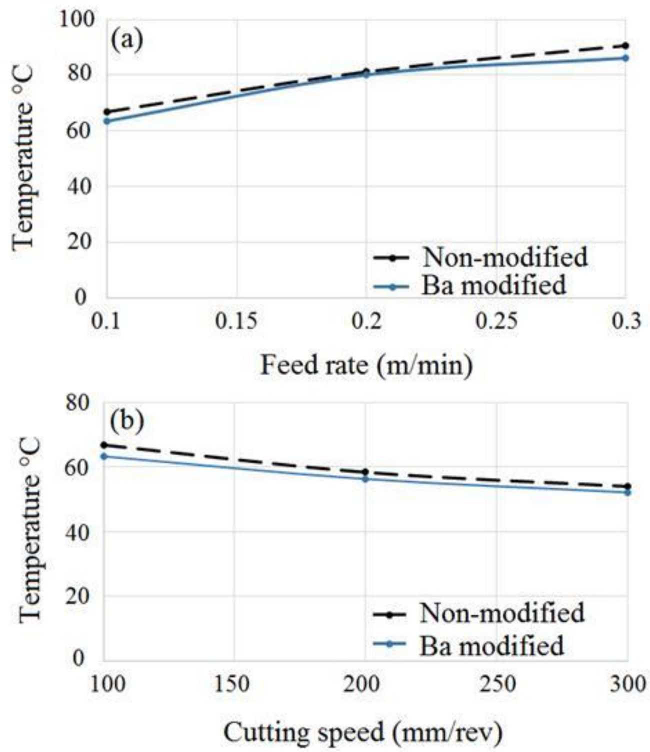

Figure 4. Temperature dependency of feed rate and cutting speed

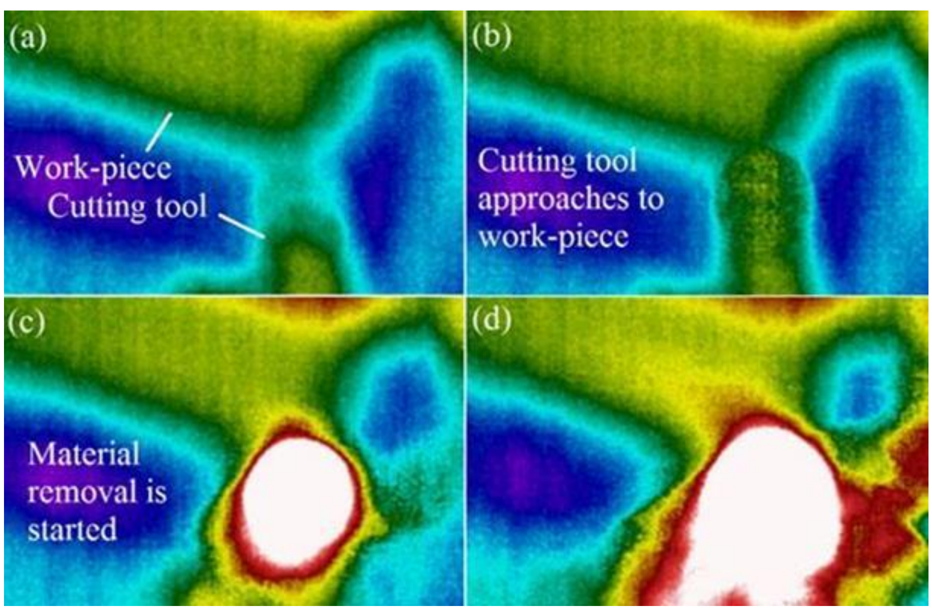

Figure 5. Cutting temperature variation

3.3 Surface roughness

The measured surface roughness for all combination of machining parameters is tabulated in Table 3. The surface roughness became worse in all work-pieces as feed rate increased from 0.1 to 0.3 mm/rev due to higher load on the tool and consequently increasing surface roughness. In addition higher values of feed rate result in domination of feed mark as well as increase distance between peaks and valleys and worsening the surfaces [17]. The results indicate the reduction in surface roughness values, while cutting speed was increased from 100 to 300 m/min which is due to making the creation and separation BUE cycle time shorter and the size of BUE smaller if the BUE forms like a heap on the tool tip, deteriorates the surface roughness. The modified work-piece presented better surface (lower Ra) in comparison to non-modified specimen in all combination of cutting speed and feed rate. Because the particle density in modified work-piece is higher than non-modified one and the BUE formation and separation cycle becomes short.

Table -3 Surface roughness for modified and non-modified specimens

No.	Cutting speed (m/min)	Feed rate (mm/rev)	Average surface roughness (non-modified, µm)	Average surface roughness (modified, µm)
1	100	0.1	3.48	3.40
2	200	0.1	3.03	2.67
3	300	0.1	2.54	1.72
4	100	0.2	4.55	3.64
5	200	0.2	3.79	3.66
6	300	0.2	3.35	2.9
7	100	0.3	6.78	5.91
8	200	0.3	6.28	5.11
9	300	0.3	6.17	4.68

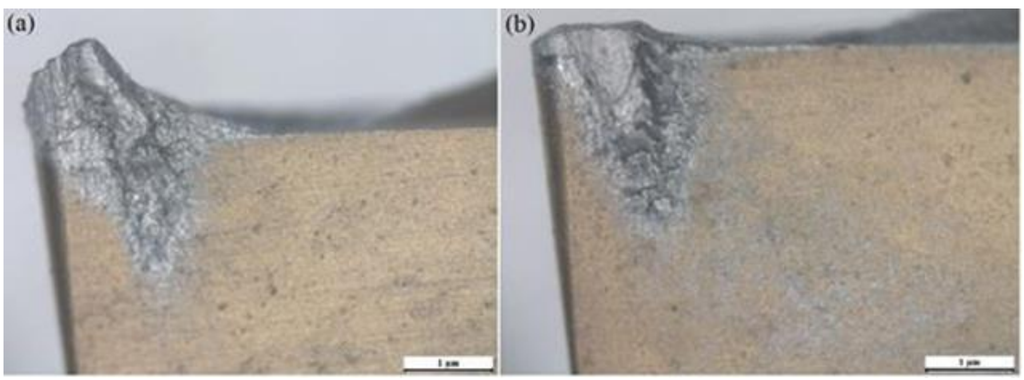

FIGURE 6. Built-up edge formation on insert rake face (a) non-modified work-piece, and (b) modified work-pieces with (b) 0.2 wt.% Ba.

Besides the lower tendency to form BUE by Ba modified specimen, it provides smaller particle size with comparison to non-modified work-piece which encourages better surface quality with respect to scenarios about particles behavior under load imposed by cutting tool tip [13, 17]. The effect of microstructure can be study and justify with respect to these scenarios.

IV. CONCLUSION

The machinability of Al-Mg_2Si in-situ composite with and without the addition of Ba addition was evaluated when dry turning was applied at cutting speeds of 100 to 300 m/min, feed rates of 0.1 to 0.3 mm/rev, and at a constant depth of cut of 0.5 mm. The following conclusions can be drawn:

1. Results show that the Ba can alter the morphology of coarse polyhedral Mg_2Si reinforcements to cubic shape when the mean size and aspect ratio decreased by 25% and 8% respectively, and the mean density increased by 33%.
2. The surface roughness was affected by the work-piece material and BUE formation. The smaller Mg_2Si reinforcements enabled lower surface roughness. Moreover, the BUE formation tendency was reduced and produced chips became brittle as the particle density increased, which led to reduce surface roughness, friction and temperature in the cutting zone.

V. REFERENCE

[1] L. Lu, K.K. Thong, M. Gupta, “Mg-based composite reinforced by Mg_2Si”, Journal of Compos Science and Technology, Elsevier, vol. 63, pp. 627–632, 2003.
[2] M. Mabuchi, K. Higashi, “Strengthening mechanisms of Mg–Si alloys”, Acta Materialia, Elsevier, vol. 44, pp. 4611–4618, 1996.
[3] S. Farahany, H. Ghandvar, N.A. Nordin, A. Ourdjini, M. H. Idris, “Effect of Primary and Eutectic Mg_2Si Crystal Modifications on the Mechanical Properties and Sliding Wear Behavior of an Al–20Mg_2Si–2Cu–xBi Composite”, Journal of Materials Science & Technology, Elsevier, vol. 32, pp. 1083-1097, 2016.
[4] Y.G. Zhao, Q.D. Qin, Y.H. Liang, W. Zhou, Q.C. Jiang, “In-situ Mg_2Si/Al–Si–Cu composite modified by strontium,” Journal of Material Science, Springer, vol. 40, pp. 1831–1833, 2005.
[5] R. Hadian, M. Emamy, N. Varahram, N. Nemati, “The effect of Li on the tensile properties of cast Al–Mg_2Si metal matrix composite,” Materials Science and Engineering A, Elsevier, vol. 490, pp. 250–257, 2008.
[6] Q.D. Qin, Y.G. Zhao, W. Zhou, P.J. Cong, “Effect of phosphorus on microstructure and growth manner of primary Mg_2Si crystal in Mg_2Si/Al composite,” Materials Science and Engineering A, Elsevier, vol. 447, pp. 186–191, 2007.
[7] M. Emamy, H.R. Jafari Nodooshan, A. Malekan, “The microstructure, hardness and tensile properties of Al–15%Mg_2Si in situ composite with yttrium addition,” Materials and Design, Elsevier, vol. 32, pp. 4559–4566, 2011.
[8] M.R. Ghorbani, M. Emamy, R. Khorshidi, J. Rasizadehghani, A.R. Emami, “Effect of Mn addition on the microstructure and tensile properties of Al–15%Mg_2Si composite,” Materials Science and Engineering A, Elseveier, vol. 550, pp. 191– 198, 2012.
[9] S. Farahany, H. Ghandvar, N.A. Nordin, A. Ourdjini, “Microstructure characterization, mechanical, and tribological properties of slow-cooled Sb-treated Al-20Mg_2Si-Cu in-Situ composites,” Journal of Materials Engineering and Performance, Springer, vol. 26, pp. 1685–1700, 2017.
[10] J. Zhang, Z. Fan, Y.Q. Wang, B.L. Zhou, “Microstructural development of Al–15wt. %Mg_2Si in-situ composite with mischmetal addition,” Materials Science and Engineering A, Elsevier, vol. 281, pp. 104–112, 2000.
[11] H. Ghandvar, M. H. Idris, N. Ahmad, M. Emamy, “Effect of gadolinium addition on microstructural evolution and solidification characteristics of Al-15%Mg_2Si in-situ composite,” Materials Characterization, Elsevier, vol. 135, pp. 57–70, 2018.
[12] A. Razavykia, S. Farahany, N.M. Yusof, “Evaluation of cutting force and surface roughness in the dry turning of Al–Mg_2Si in-situ metal matrix composite inoculated with bismuth using DOE approach,” Measurement, Elsevier, vol. 76, pp. 170–182, 2015.
[13] N.M. Yusof, A. Razavykia, S. Farahany, A. Esmaeilzadeh, “Effect of modifier elements on machinability of Al-20%Mg_2Si metal matrix composite during dry turning,” Machining science and technology, Taylor and francis, vol. 20, pp. 460-474, 2016.
[14] A. Knuutinen, K. Nogita, S.D. McDonald, A.K. Dahle, “Modification of Al–Si alloys with Ba, Ca, Y and Yb,” Journal of Light Metals, Elsevier, vol. 1, pp. 229-240, 2001.
[15] K. Chen, Z.Q. Li, J.S. Liu, J.N. Yang, Y.D. Sun, S.G. Bian, “The effect of Ba addition on microstructure of in- situ synthesized Mg_2Si/Mg–Zn–Si composites,” Journal of Alloys and Compounds, Elsevier, vol. 487, pp. 293-297, 2009.
[16] K. Palanikumar, N. Muthukrishnan, K. S. Hariprasad,“Surface roughness parameters optimization in machining A356/SiC/20p metal matrix composites by PCD tool using response surface methodology and desirability function,” Machining Science and Technology, Taylor and francis, vol. 12, pp. 529-545, 2008.
[17] A. Pramanik, L. C. Zhang, J. A. Arsecularatne, An FEM investigation into the behavior of metal matrix composites: tool–particle interaction during orthogonal cutting,” International Journal of Machine Tools and Manufacture, Elseveier, vol. 47, pp. 1497-1506, 2007.