

H. RUDIANTO*[#], G.J. JANG**, S.S. YANG**, Y.J. KIM**, I. DLOUHY*

EFFECT OF SiC PARTICLES ON SINTERABILITY OF Al-Zn-Mg-Cu P/M ALLOY

WPLYW CZĄSTEK SiC NA SPIEKALNOŚĆ PROSZKU STOPOWEGO Al-Zn-Mg-Cu

Premix Al-5.5Zn-2.5Mg-0.5Cu alloy powder was analyzed as matrix in this research. Gas atomized powder Al-9Si with 20% volume fraction of SiC particles was used as reinforcement and added into the alloy with varied concentration. Mix powders were compacted by dual action press with compaction pressure of 700 MPa. High volume fraction of SiC particles gave lower green density due to resistance of SiC particles to plastic deformation during compaction process and resulted voids between particles and this might reduce sinterability of this mix powder. Sintering was carried out under ultra high purity nitrogen gas from 565°-580°C for 1 hour. High content of premix Al-5.5Zn-2.5Mg-0.5Cu alloy powder gave better sintering density and reached up to 98% relative. Void between particles, oxide layer on aluminum powder and lower wettability between matrix and reinforcement particles lead to uncompleted liquid phase sintering, and resulted on lower sintering density and mechanical properties on powder with high content of SiC particles. Mix powder with wt90% of Alumix 431D and wt10% of Al-9Si-vf20SiC powder gave higher tensile strength compare to another mix powder for 270 MPa. From chemical compositions, sintering precipitates might form after sintering such as MgZn₂, CuAl₂ and Mg₂Si. X-ray diffraction, DSC-TGA, and SEM were used to characterize these materials.

Keywords: metal matrix composites, powder metallurgy, sintering, heat treatment

1. Introduction

SiC particle is well known ceramic materials which added into the metal matrix to improve mechanical and thermal properties due to its high strength and thermal resistance. Aluminum metal matrix composite has been attracted many researchers to apply into automotive and aerospace industry as a lightweight material. SiC reinforced Aluminum matrix has been investigated with different methods such as casting and mechanical alloying. Conventional sintering based process of SiC reinforced aluminum matrix is rarely observed, due to low wettability of SiC particle to aluminum matrix. SiC has high melting point approximately 2730°C and it hinders interparticle diffusivity during sintering of aluminum powder. Gas atomization process of powder production successfully made intragranular SiC inside aluminum matrix which showed better wettability between SiC and aluminum matrix [1-2].

Sintering based process of metal matrix composite such as SiC reinforced aluminum matrix is an alternative process to produce low cost manufacturing of aluminum based parts. Conventional sintering behavior of aluminum alloy powder was investigated by many researchers. Nitrogen gas atmosphere seem to be suitable atmosphere during sintering as it helps during pore filling process and activate magnesium to remove oxide layer on aluminum particle. Reaction between

magnesium and oxide layer was recorded with atomic absorption process by T. Pieczonka et al [2-5].

In this research, intragranular SiC particle inside aluminum matrix was added into premix Al-5.5Zn-2.5Mg-0.5Cu alloy powder. The purpose of this research is to investigate effect of volume fraction of SiC from gas atomized Al-Si-SiC powder on premix Al-5.5Zn-2.5Mg-0.5Mg alloy powder.

2. Experimental

Premix Al-5.5Zn-2.5Mg-0.5Mg powder was prepared by Ecka Granules, Germany, named Alumix 431D. Intragranular SiC was obtained from Al-9Si with 20% volume fraction of SiC (12 μm) and prepared by gas atomization process in Powder Technology Research Group, Korea Institute of Materials Science. Powders were mixed with different composition of Al-9Si-vf20SiC(12 μm). Ethylene bis stearamide solid lubricant was added into mix powder to improve its compactibility. And powders were mixed by turbula mixer for 30 min.

Sintering was carried out under ultra high purity nitrogen gas. Sintering temperature range is from 560-580°C and hold for 1 hour. Prior to reach sintering temperature, compacted powders were delubricated at 400°C for 30 min. Sintering density was done by Archimedes method. T6 heat treatment was done to possibly form strengthening precipitates. Sintered

* INSTITUTE OF MATERIALS SCIENCE AND ENGINEERING, NETME CENTER, BRNO UNIVERSITY OF TECHNOLOGY, BRNO, CZECH REPUBLIC

** POWDER TECHNOLOGY RESEARCH GROUP, KOREA INSTITUTE OF MATERIALS SCIENCE, CHANGWON, REPUBLIC OF KOREA

[#] Corresponding author: harisrudianto@gmail.com

materials were solid solutionized at 475°C followed by water quenching and artificial aging at 125°C for 24 hour. Powders were characterized by optical microscopy, SEM, DSC-TGA, and XRD. Hardness and tensile tests were done to observe mechanical properties of this material.

3. Results and discussion

From Fig. 1 shows that SiC particle is finely dispersed throughout aluminum matrix. Intragranular SiC particle shows better wettability with aluminum matrix. To investigate thermal behavior of mix powder, DSC-TGA analysis was carried out. From 50:50 ration, DSC graph has several peaks starting with eutectic reaction of Al-Mg following with Al-Cu, Al-Si and Al-Zn. TG graph as shown by green line, the line starts to fall down at 340°C, this supposed to be delubrication process. Lubricant must be removed before sintering to prevent possible chemical reaction between powder, lubricant and atmosphere. Lubricant usually has low melting point. Ethylene bis stearamide has low melting point of 340°C. TG line is going up starting at 430°C, this means there is gaining mass at starting at this temperature. Possibility of reaction between aluminum and nitrogen gas is expected.

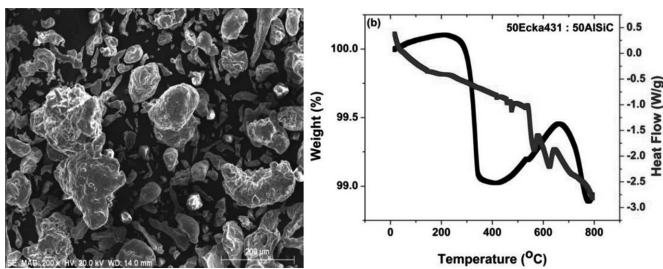


Fig. 1. (a) microstructure and (b) mix powder with 50:50 ratio and its DSC-TGA graph a function of temperature (heating rate of 50°C/min)

SiC particle has high resistant to deformation. Fig. 2 show the trend of green density depending on their chemical composition. High volume fraction of SiC reduced green density due to its resistant to deformation during compaction process and possibility to have entrapped gas is highly expected. Ecka alumix 431D has high compactibility with reaching highest green density of 94% relative.

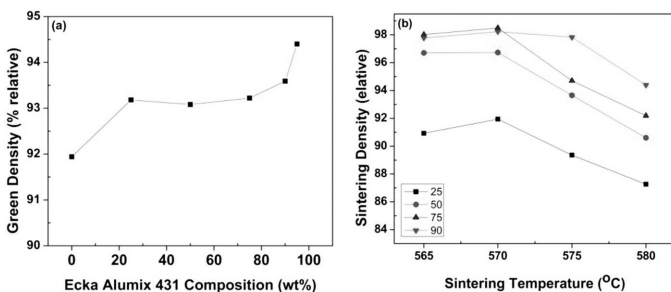


Fig. 2. (a) Green density and (b) Sintering density of mix powder

Sintering was carried out under ultrahigh purity nitrogen gas of 99.9999% purity. Sintering density increased with increasing sintering temperature but it also depends on chemical composition. Higher weight percent of Ecka Alumix 431D, higher optimum sintering temperature, this due to Ecka Alumix 431D has higher melting point compare to Al-Si-SiC alloy powder. Fig. 3 shows microstructure of sintered at 570°C of

mix powder with 90wt% of Ecka Alumix 431D, it shows high densification in body center and surface. Some SiC particles agglomerated, this probably related to mixing process. Other than that, it shows fine grain microstructure.

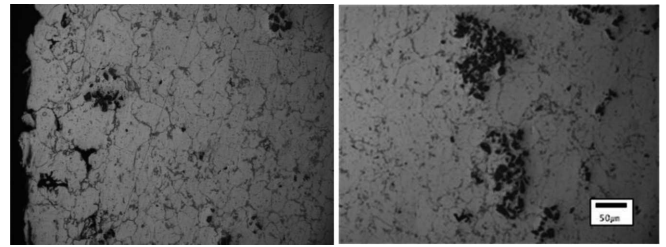


Fig. 3. Microstructure of sintered powder with 90wt% of Ecka Alumix 431D

Tensile strength also shows same trend with sintering density. Big amount of Alumix 431D gave higher sintering density compared to materials with high volume fraction of SiC. Pure Alumix 431D shows highest tensile strength and reached 329 MPa. Quite interesting that SiC particles did not improve mechanical properties of this material. This assumes that SiC did not bond strong enough to aluminum matrix even after compacted at high pressure. SiC has high melting point, this probably the reason of lower diffusivity into aluminum matrix. Lower diffusivity will give lower chemical bonding between particles and leading to lower sintering density and mechanical properties. Fig. 4b shows x-ray diffraction analysis, α aluminum has dominant peaks followed by Si and SiC. Intermetallic phases also present at this sintered materials such as $MgZn_2$, $CuAl_2$, $AlFe$ and Mg_2Si .

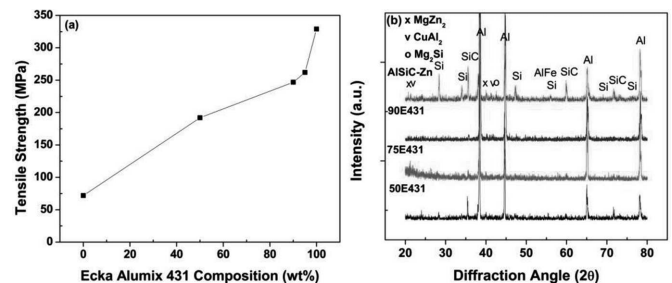


Fig. 4. (a) Tensile strength of sintered mix powder depending on content of Ecka Alumix 431D (b) X-ray diffraction analysis of sintered materials with 50,75, 90wt% of Ecka Alumix 431D and Al-Si-SiC alloy powder

Distribution of alloying element of sintered sample is shown below by using EDS analysis. From first picture at Fig. 5, there are precipitates as a result from sintering inside grain and in grain boundary. These precipitates are expected and analyzed by using XRD at Fig. 4(b). Aluminum is homogeneously dispersed throughout the sample as well as Zinc and Copper. And SiC shows in bright color with combination of color of Si and C. Mg is decomposed into grain boundary, this is related to reaction between Mg and oxide layer on aluminum particle to form spinel, $MgAl_2O_4$ during sintering. This is supported by presence of oxide in grain boundary. According to DSC graph at Fig. 1(b), there is reaction between Al-Mg, and this is supposed to be removing of oxide layer, Al_2O_3 . This reaction is important for wettability of aluminum particle to obtain high sintering density, as oxide layer has high melting point, it decreases sinterability of aluminum. So,

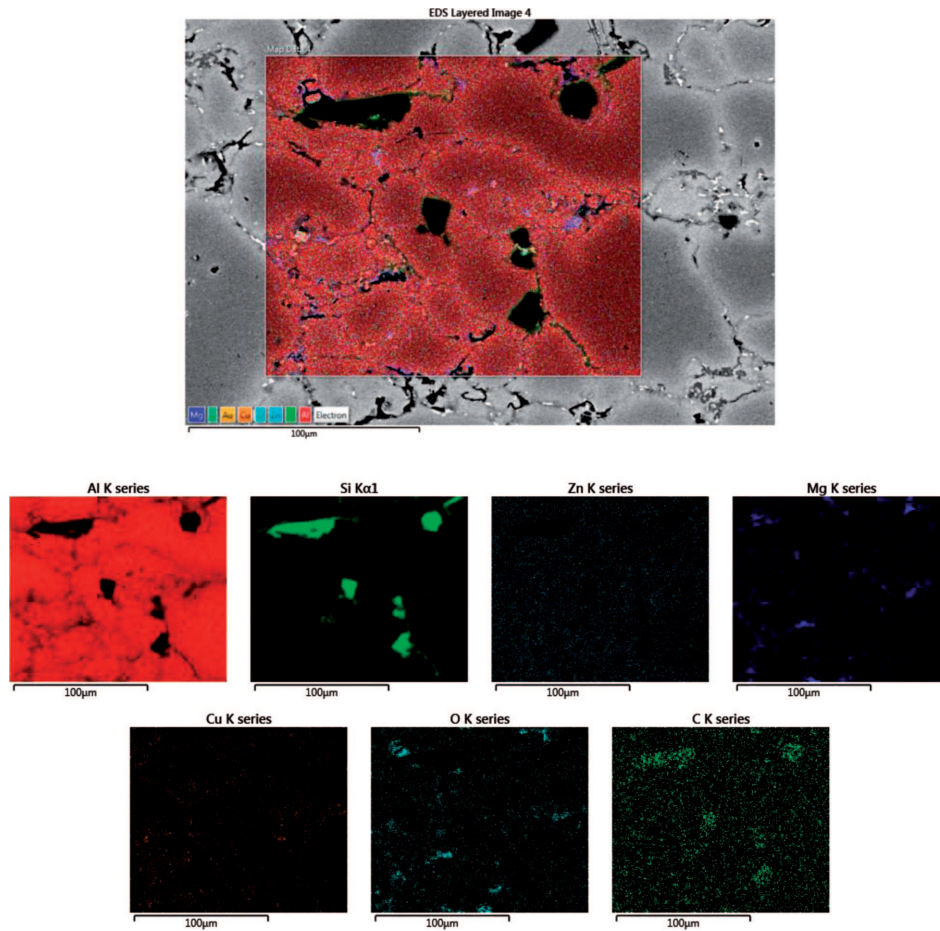


Fig. 5. EDS analysis of sintered sample with 50wt% of Al-Si-SiC powder

removing oxide layer at lower temperature is demanding, and Mg is more reactive at lower temperature. This phenomenon also shows by N. Showaiter et al and T. Pieczonka about Mg behavior on sintering of aluminum powder [3, 6].

4. Conclusions

Al-5.5Zn-2.5Mg-0.5Cu powder shows high sintering density by having more than 98% relative density, and it decreases with adding more SiC particles. These phenomena due to plasticity resistance of SiC particles during compaction and results on void between particles and leads to lower sintering density for mix powders. Chemical compositions have important role on determining of optimum sintering temperature as these two powders have slightly different melting point. Pure Al-5.5Zn-2.5Mg-0.5Cu has optimum sintering temperature at 580°C but it decreased with adding Al-Si-SiC powder to 570°C. Sintering density is linear with mechanical properties, high amount of SiC particles inside matrix reduced mechanical properties. From EDS analysis, sintered mix powder has homogenously dispersed elements. Precipitates as a result from sintering are $MgZn_2$, $CuAl_2$ and Mg_2Si and these

are responsible for presence of precipitates inside grain and in grain boundary as shown by SEM-EDS.

Acknowledgements

This research was mainly supported by Ministry of Knowledge and Economics, Republic of Korea under Fundamental R&D program for Core Technology of Materials and partially funded by Project Excellent CZ.1.07/23.00/30.0005, Czech Republic.

REFERENCES

- [1] V. Laurent, D. Chatain, N. Eustathopoulos, *J. Mater. Sci.* **22**, 244-250 (1987).
- [2] H. Rudianto, Y. Sang Sun, K. Yong Jin, N. Ki Woo, *Inter. J. Modern. Physics: Conference Series.* **6**, 628-633 (2012).
- [3] T. Pieczonka, Th. Schubert, S. Baunack, B. Kieback, *Mater. Sci. Eng. A* **478**, 1-2, 251-256 (2008).
- [4] G.B. Schaffer, B.J. Hall, S.J. Bonner, S.H. Huo, T.B. Sercombe, *Acta Materialia* **54**, 1, 131-138 (2006).
- [5] H. Rudianto, Y. Sang Sun, N. Ki Woo, K. Yong Jin, *Rev. Adv. Mater. Sci.* **28**, 2, 145-149 (2011).
- [6] N. Showaiter, M. Youseffi, *Materials and Design.* **29**, 752-762 (2008).