Antin, Kim-Niklas; Jalava, Kalle

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MECHANICAL PROPERTIES OF CAST ALUMINIUM MATRIX COMPOSITES REINFORCED WITH SIC AND AL2O3 PARTICLES

Kim-Niklas Antin[1] and Kalle Jalava[1]

[1]Department of Engineering Design and Production, Aalto University
Puumiehenkuja 3, 02150 Espoo, Finland
Email: kim-niklas.antin@aalto.fi, web page: http://www.aalto.fi

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ABSTRACT

Aluminium matrix composites have the potential to be high performance materials. The main benefits being higher strength, stiffness, wear resistance and thermal conductivity compared to the matrix material alone. However, the down sides are loss in ductility, fracture toughness and difficult processing routes.

We use state-of-the-art processing parameters to produce an aluminium matrix composite with 30 µm micro-SiC particles together with 50 nm nano-Al_2O_3 particles. Both reinforcements have been used separately before, but we study whether or not additional benefits can be achieved by using different sized reinforcements in the same composite.

1 INTRODUCTION

Metal matrix composites (MMC) can show superior properties, such as higher stiffness and strength, compared to the matrix material alone. There are many routes for processing MMCs [1], but casting is the most viable. The reinforcement is usually silicon carbide (SiC) or aluminium oxide (Al_2O_3).

Hashim et al. has extensively reported the four challenging aspects in processing Al-SiC composites using the casting route [2-5]. Firstly, uniform distribution of reinforcement particles was found to be difficult to achieve. Factors affecting the distribution are: type of particle introduction (vortex stirring [6], gas injection etc.), holding time [7], pouring rate, pouring temperature, gating systems, particle migration on freezing fronts, solidification rate etc. The second factor to consider is wettability. Wettability can be promoted using coatings, additional alloying elements, heat treatment of particles, ultrasonication and mechanical stirring in semi-solid state. Thirdly, porosity tends to increase as particle size decreases or their amount is increased. Sources of porosity are gas entrapment during mixing, gas layers on reinforcement particles, gas trapped during injection of particles, gas drawn into the melt during pouring and solidification shrinkage. Lastly, the viscosity of the melt is increased as particle content rises or particle size decreases. The chemical reaction forming Al_4C_3 will also increase viscosity and must be avoided. The same conclusions were made by Amirkhanlou in two duplicate publications [8-9].

The mechanical properties of Al-SiC composites has been studied extensively. Singla et al. reported in a partly plagiarized article an increase in hardness as particle content increases [10]. However, hardness or compression tests do not show the effect of porosity. Increased SiC content has been shown to result in higher tensile strength, but the effect on fracture toughness or impact toughness is negative or neutral respectively [11-12]. A decrease in fatigue strength is reported [13], while others have seen an increase [14] as particle content increases. However, the latter article by Skolianos had very low Young's modulus values (10-20 GPa) which undermines the reliability of the results.

Adding aluminium oxide to aluminium alloys has been reported in a series of redundant/duplicate publications by Mazahery, Saijjadi and Tahamtan [15-19]. They found that adding Al_2O_3 particles increases strength up to 2% weight fraction after which increased porosity begins to offset the gains. Ball milling the Al_2O_3 particles together with aluminium particles reduces porosity compared to adding the oxide particles alone. The grain size was reduced significantly by the nano- Al_2O_3 particles. Wettability of nanoparticles was found to be inferior compared to microparticles, but injection using an inert gas carrier and heat treatment of particles could be used to improve wettability. Improved mechanical properties are seen, for example in wear [20].

The aim of this study is to investigate if using two different sized reinforcements, namely microsized silicon carbide and nanosized aluminium oxide, brings any additional benefits compared to using either alone.

2 METHODS

Three materials were studied in two different conditions each. The investigated alloys are A356, A359-20%SiC and A359-20%SiC-1%Al_2O_3. The two conditions are as-fabricated (F) and T6 (solution annealed, quenched and peak aged [21]). The A356 alloy was melted from primary ingots in a radiation furnace, modified and grain refined. The SiC composite was also melted from primary ingot, whereas the SiC+Al_2O_3 MMC was made by mixing 50 nm nano-Al_2O_3 with Al-powder and packing the mixture in aluminium foil. The foil packets were submerged into the melt and a graphite stirrer was used at 300 rpm at 1/3 depth in the graphite crucible for 15 minutes total. The stirring temperature was under 700°C, but the alloy was reheated to 760°C before pouring into a pre-heated (400°C) steel mould.

The cast tensile test specimens were pulled in a 100 kN MTS tensile machine at a rate of $3 \cdot 10^{-4}$. The round tensile test specimens had a gauge length of 50 mm and 12,7 mm diameter. Strain was measured using a digital image correlation (DIC) software from LaVision GmbH. The pattern on the sample (Figure 1) was optimized for contrast and feature size [22]. A frame rate of 1 Hz was used and the image sequence was analysed to obtain the strains in tensile direction. A virtual strain gage was used to obtain average strain over the gauge length.

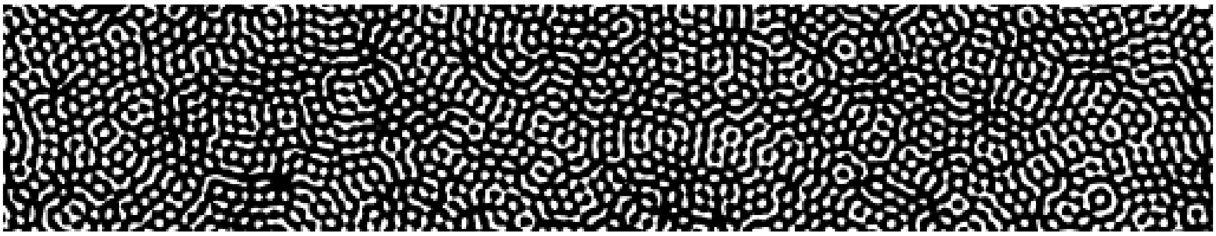

Figure 1: Optimized pattern for DIC [22].

3 RESULTS

The strain field was generally very uniform and the virtual strain gauge can be trusted. In the A356-T6 some local deformation was visible already at low strains (Figure 2). This could be due to a pore causing local stresses.

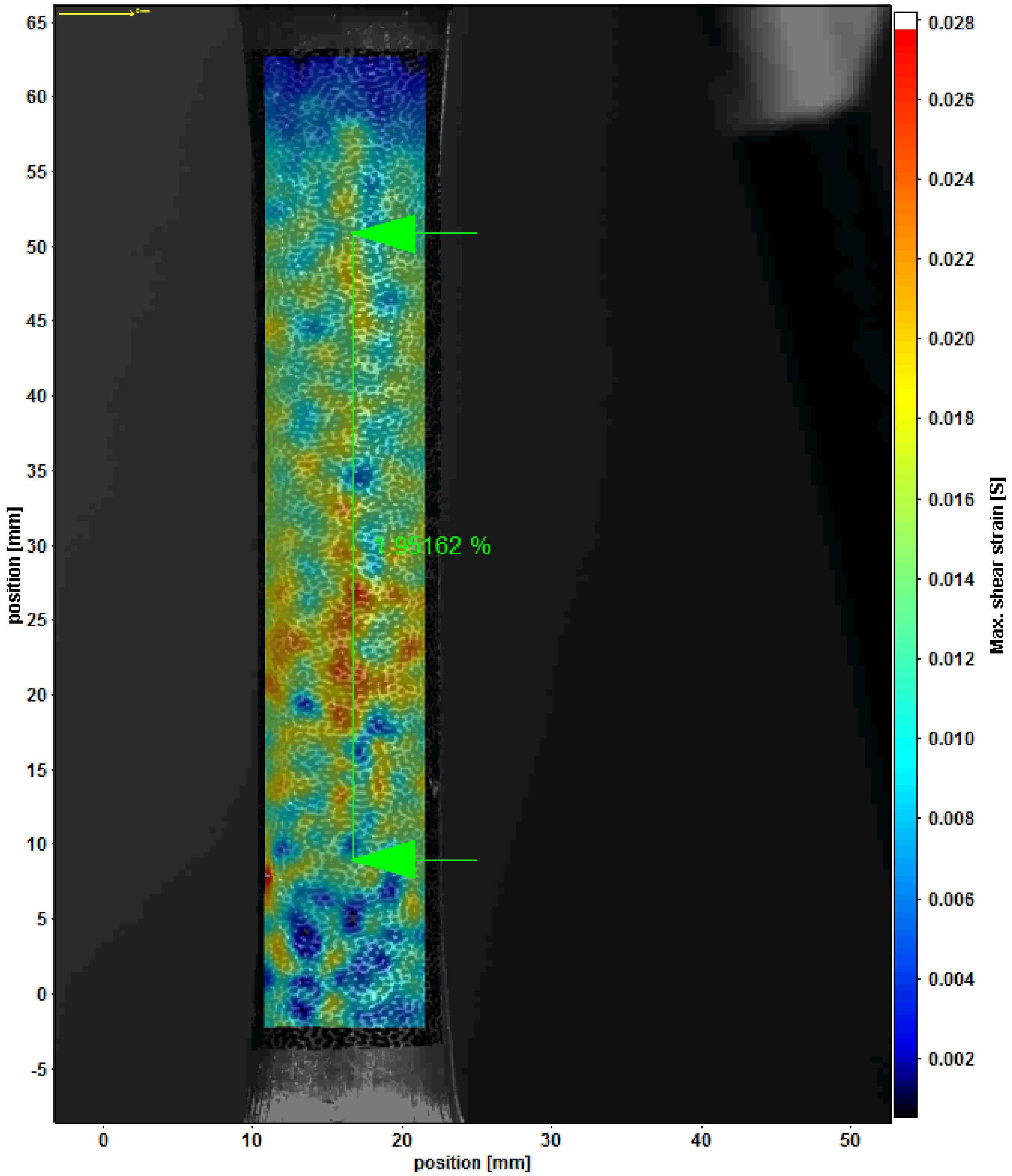

Figure 2: Shear strain fields of A356-T6 at 2% extension.

The true stress-true strain curves obtained using the virtual strain gauge can be seen in Figure 3. The A356-F sample has the lowest yield strength and highest ductility as can be expected. Heat treatment improved yield strength at the expense of ductility. The highest strength is seen with Al-SiC-T6 MMC, but the plastic elongation is almost non-existent.

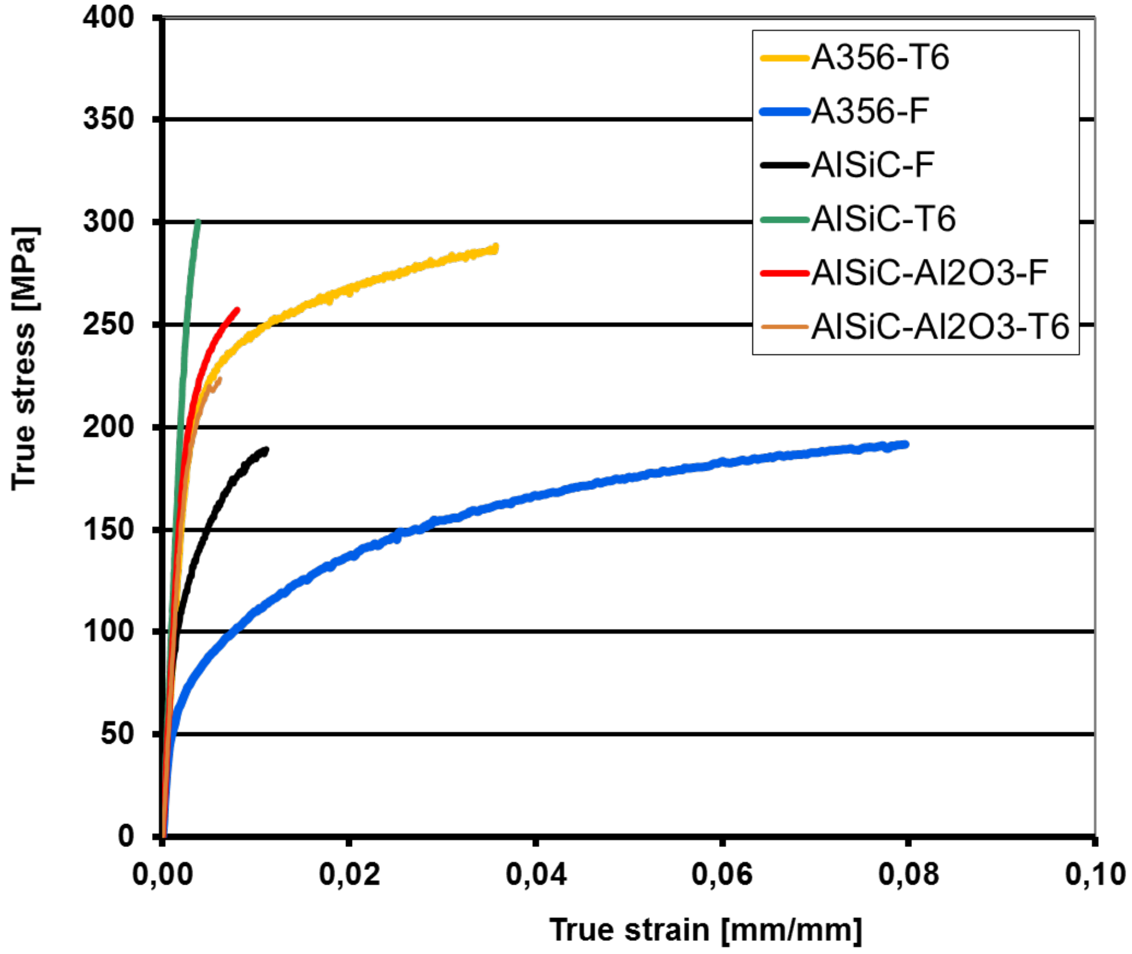

Figure 3: True stress-true strain curves of the tested alloys.

The addition of 20 w-% silicon carbide should have a dramatic effect on the Young's modulus of cast aluminium alloys. Indeed, an increase from 75 GPa to 106 GPa is seen for the T6 condition (Table 1). Adding aluminium oxide made the situation worse. This could be due to settling of the SiC particles during the holding time. The holding time was longer with the aluminium oxides because mixing times were longer and therefore the time to heat the melt to pouring temperature and the amount of slag that had to be skimmed was higher.

Table 1: Summary of mechanical properties.

Sample name	Youngs Modulus [GPa]	Rp0,1 [MPa]	Rm [MPa]	Ag [%]
A356-F	58	69	177	8,0
A356-T6	75	205	278	3,2
AlSiC-F	98	114	187	0,9
AlSiC-T6	106	299	299	0,1
AlSiC-Al2O3-F	88	213	255	0,5
AlSiC-Al2O3-T6	84	195	222	0,3

The fracture surfaces of the composites showed pores (Figure 4).

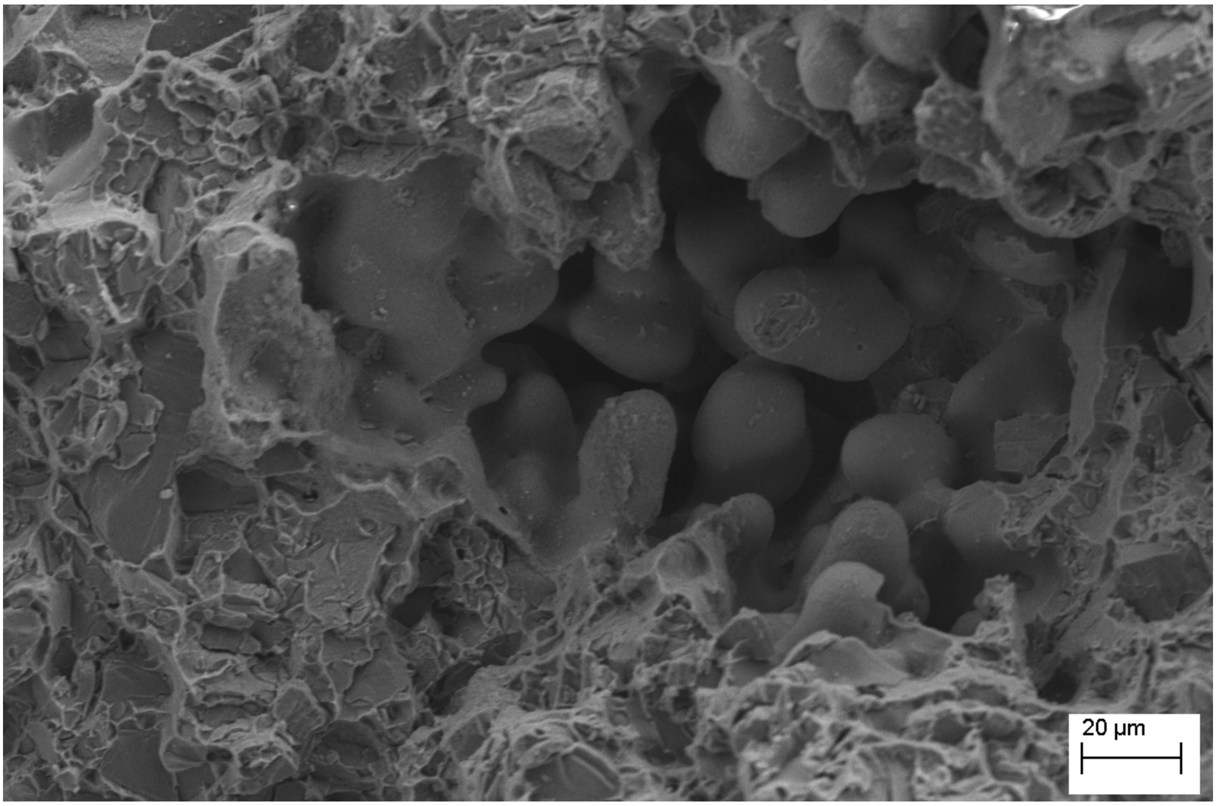

Figure 4: Fractograph of the Al-SiC composite after tensile testing.

4 DISCUSSION

Silicon carbide reinforced cast aluminium alloys can show significant gains in stiffness and yield strength compared to the unreinforced matrix. Heat treating them is highly beneficial. This is probably due to spheroidization of the silicon phase during solution annealing. Adding aluminium oxide nanoparticles proved to be difficult due to poor wetting properties of the high surface area of the nanoparticles and the high viscosity of the Al-SiC melt. The apparent need for complicated processing routes undermines any possible gains in mechanical properties. The lack of ductility of MMCs makes them hard to use in engineering because their capacity to accommodate defects is low. A modified and grain refined A356-T6 alloy performs very well against the MMCs with respect to mechanical properties.

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REFERENCES

[1] D.K. Koli, G. Agnihotri and R. Purohit, A review on properties, behaviour and processing methods for Al-nano Al2O3 composites, *Procedia Materials Science,* **6**, 2014, pp. 567-589 (doi:10.1016/j.mspro.2014.07.072).

[2] J. Hashim, L. Looney and M.S.J. Hashmi, Metal matrix composites: production by the stir casting method, *Journal of Materials Processing Technology*, **92-93**, 1999, pp. 1-7.

[3] J. Hashim, L. Looney and M.S.J. Hashmi, The enhancement of wettability of SiC particles in cast aluminium matrix composites, *Journal of Materials Processing Technology*, **119**, 2001, pp. 329-335.

[4] J. Hashim, L. Looney and M.S.J. Hashmi, Particle distribution in cast metal matrix composites – Part I, *Journal of Materials Processing Technology*, **123**, 2002, pp. 251-257.

[5] J. Hashim, L. Looney and M.S.J. Hashmi, Particle distribution in cast metal matrix composites – Part I, *Journal of Materials Processing Technology*, **123**, 2002, pp. 258-263.

[6] S.B. Prabu, L. Karunamoorthy, S. Kathiresan and B. Mohan. Influence of stirring speed and stirring time on distribution of particles in cast metal matrix composite, *Journal of Materials Processing Technology*, **171**, 2006, pp. 268-273.

[7] A. Ourdjini, K.C. Chew and B.T. Khoo. Settling of silicon carbide particles in cast metal matrix composites, *Journal of Materials Processing Technology*, **116**, 2001, pp. 72-76.

[8] S. Amirkhanlou and B. Noroumand, Synthesis and characterization of 356-SiCp composites by stir casting and compocasting methods. *Transaction of Nonferrous Metals Society of China* **20**, 2010, pp. 788-793.

[9] S. Amirkhanlou and B. Niroumand. Development of Al356/SiCp cast composites by injection of SiCp containing composite powders. *Materials and Design* **32**, 2011, pp. 1895-1902. (doi: 10.1016/j.matdes.2010.12.013).

[10] M. Singla, D.D. Dwivedi, L. Singh and V. Chawla. Development of aluminium based silicon carbide particulate metal matrix composite, *Journal of Minerals & Materials Characterization & Engineering*, **8**, 2009, pp. 455-467

[11] K.K. Alaneme and A.O. Aluko, Fracture toughness (K1C) and tensile properties of as-cast and age-hardened aluminium (6063)-silicon carbide particulate composite, *Scientia Iranica A*, **19**, 2012, pp. 992-996 (doi: 10.1016/j.scient.2012.06.001).

[12] A.R.I. Kheder, G.S. Marahleh and D.M.K. Al-Jamea, Strenghening of aluminium by SiC, Al2O3 and MgO, *Jordan Journal of Mechanical and Industrial Engineering*, **5**, 2011, pp. 533-541.

[13] P.K. Rohatgi, S. Alaraj, R.B. Thakkar and D. Daoud, Variation in fatigue properties of cast A359-SiC composites under total strain controlled conditions: Effect of porosity and inclusions, *Composites: Part A*, **38**, 2007, pp. 1829-1841 (doi:10.1016/j.compositesa.2007.04.005).

[14] S. Skolianos, Mechanical behavior of cast SiCp-reinforced Al-4.5%Cu-1.5%Mg alloy, *Materials Science and Engineering A*, **210**, 1996, pp. 76-82.

[15] A. Mazahery, H. Abdizadeh and H.R. Baharvandi, Development of high-performance A356/nano-Al2O3 composites, *Material Science and Engineering A* **518**, 2009, pp. 61-64 (doi: 10.1016/j.msea.2009.04.014).

[16] S.A. Sajjadi, H.R. Ezatpour and H. Beygi, Microstructure and mechanical properties of Al-Al2O3 micro and nano composites fabricated by stir casting, *Material Science and Engineering A* **528**, 2011, pp. 8765-8771 (doi: 10.1016/j.msea.2011.08.052).

[17] S.A. Sajjadi, H.R. Ezatpour and M. Torabi Parizi, Comparison of microstructure and mechanical properties of A356 aluminium alloy/Al2O3 composites fabricated by stir and compo-casting processes, *Materials and Design* **34**, 2012, pp. 106-111 (doi: 10.1016/j.matdes.2011.07.037).

[18] S.A. Sajjadi, M. Torabi Parizi, H.R. Ezatpour and A. Sedghi, Fabrication of A356 composite reinforced with micro and nano Al2O3 particles by a developed compocasting method and study of its properties. *Journal of Alloys and Compounds* **511**, 2012, pp. 226-231 (doi: 10.1016/j.jallcom.2011.08.105).

[19] S. Tahamtan, A. Halvaee, M. Emamy and M.S. Zabihi. Fabrication of Al/A206-Al2O3 nano/micro composite by combining ball milling and stir casting technology, *Materials and Design*, **49**, 2013, pp. 347-359 (doi: 10.1016/j.matdes.2013.01.032).

[20] V. Bharat, M. Nagaral, V. Auradi and S.A. Kori, Preparation of 6061 Al-Al2O3 MMC's byt stir casting and evaluation of mechanical and wear properties, *Procedia Materials Science*, **6**, 2014, pp. 1658-1667 (doi: 10.1016/j.Mspro.2014.07.151).

[21] J-H. Peng, X-L. Tang, J-T. He and D-Y. Xu, Effect of heat treatment on microstructure and tensile properties of A356 alloys, *Transaction of Nonferrous Metals Society of China* **21**, 2011, pp. 1950-1956.

[22] S. Bossuyt, Optimized patterns for digital image correlation, *Proceedings of the Annual Conference on Experimental and Applied Mechanics, Costa Mesa, USA*, 2012, pp. 239-248.