Advances in Machinery, Materials Science and Engineering Application
M. Chen et al. (Eds.)

doi:10.3233/ATDE220429

Fabrication and Microstructure Characterization of Cold Sprayed Al-SiC$_p$ Nanocomposite Coating

Xudong ZHENG [a], Hongtao WANG [a,b,1], Ruoyu WANG [c], Wangnian Zhang [a,b], Xiaobo BAI [a] and Gangchang JI [a]

[a] *School of Material Science and Engineering, Jiujiang University, Jiujiang, Jiangxi, P.R. China*

[b] *Jiangxi Province Engineering Research Center of Material Surface Enhancing & Remanufacturing, Jiujiang University, Jiujiang, Jiangxi, P.R. China*

[c] *Labour Union, JiuJiang University, JiuJiang, 332005, P.R. China*

Abstract. A dense Al-SiC$_p$ nanocomposite coating with high volume fraction of nano SiC$_p$ reinforcement (60 vol.%) was fabricated through cold spraying deposition of milled Al-60SiC$_p$ nanocomposite powder in the present paper. Microstructure evolution of Al-SiC$_p$ nanocomposite powder during ball milling process, microstructure characteristics and hardness of sprayed Al-SiC$_p$ nanocomposite coating were studied. Al particles underwent fracture deformation and nano SiC particles were evenly distributed in the soft Al base material after ball milling. Dense Al-SiC$_p$ composite coating had been successfully prepared through cold spraying solidification of the milled nanocomposite powder. Nano SiC particles uniformly distributed in the as-sprayed Al-SiC$_p$ composites coating. Microhardness of Al-SiC$_p$ nanocomposite coating was highly reach up to 530±53 Hv$_{0.3}$ compared to 34±3 Hv$_{0.3}$ for the pure Al bulk.

Keywords. Cold spray, ball milling, Al-SiC nanocomposite, microstructure, microhardness

1. Introduction

Metal-matrix nanocomposites (MMNCs) are a kind of materials developed to achieve excellent mechanical and physical properties [1]. Al and its alloys are widely used for MMNCs due to their processing flexibility, good corrosion resistance and low cost [2]. Al matrix nanocomposite (AMNCs) reinforced with SiC particles have a distinct advantages for transport applications due to its low weight and high specific strength. AMNCs can be fabricated using a number of technologies including casting, sintering, hot pressing [3-5], and thermal spraying (TS) [6-7]. As far as thermal spraying was concerned, SiC particles were inclined to lost due to its high hardness and correspondingly the final AMNCs had high porosity [7]. In addition, fine SiC$_p$ particles would decompose to liquid silicon and solid carbon particles in conventional TS

[1] Hongtao Wang, Corresponding author, School of Material Science and Engineering, Jiujiang University, Jiujiang, Jiangxi, P.R. China; E-mail: wanght@jju.edu.cn.

process [7]. Hence, how to eliminate the loss and decomposition of SiC particles has been a key problem when TS were used to produce Al-SiCp nanocomposite coating.

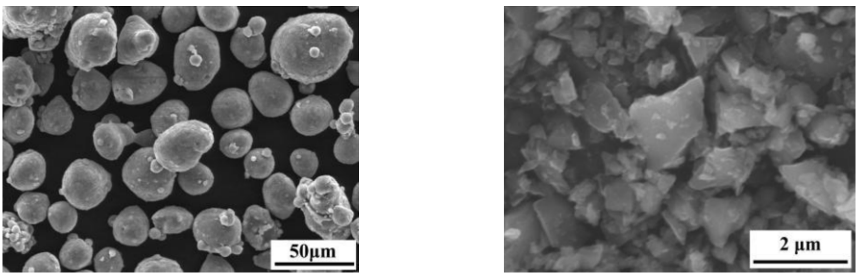
Cold spraying has been widely used to deposit metals and alloys [8], composites [9-10], and even nanostructure materials [11] due to its low deposition temperature and high deposition efficiency. In this process, particles in a solid state occur intensive plastic deformation when impacting upon substrate and /or the pre-deposited particles and consequently form a coating without the deleterious problems inherent to conventional TS, for example oxidation, phase transformation, decomposition, grain growth and etc [8]. The previous studies [9-10] showed that AMNCs can be prepared by CS using a mixed powder. Whereas, the content of reinforced particles in AMNCs was low than that in the original powder due to different deposition efficiency. Ball milling is a simple process to prepare nanocomposite powder with high volume fraction of particle reinforcement for fabricating AMNCs or AMNC coatings [12]. However, few works were dedicated to fabricate AMNC coating with high volume fraction of SiC_p (above 50 vol.%) by cold spraying.

Therefore, the aim of this paper was to cold spraying deposition of Al-60 (vol.%) SiC_p nanocomposite coating using the milled Al-SiC_p nanocomposite powder. Microstructure evolution of Al-SiC_p nanocomposite powder during ball milling and microstructure characteristics of cold-sprayed Al-SiC_p nanocomposite coating as well as its microhardness were also studied.

2. Materials and Procedures

2.1. Al-SiC Nanocomposite Powder Preparation

The elemental powder were Al (99.5 wt.%, -48 μm) as a matrix and nano SiC_p particles (0.7~1.5 μm) as an reinforcement, as shown in figure 1. Al powder was spherical and SiC powder was angular. Al-60SiC (vol.%) nanocomposite powders was prepared through ball milling. Ball milling was performed in planet style ball mill with the mass ratio of ball-to-powder about 10:1. Stearic acid (1.5 wt.%) was added to prevent agglomeration of the ductile Al powders. Powder samples were brought out at different intervals for analysis. After milling for 20 hrs, the powder was sieved to < 25 μm suitable for spraying



(a) (b)

Figure 1. SEM images of feedstock powders: Al (a) and SiC (b).

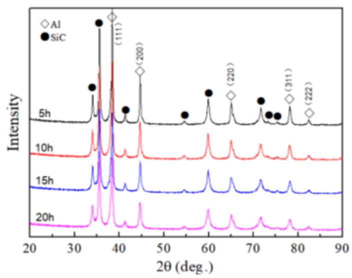
2.2. Deposition of Al-SiC Nanocomposite Coating and Characterization

A cold spraying system installed in our lab was used to prepare Al-SiC nanocompoiste. Nitrogen was used as both driving gas and powder carrier gas with a pressure of 2.8 MPa and 3.0 MPa, respectively. Driving gas temperature was about 480°C and standoff distance was 20 mm. Substrate was Al plate with the thickness about 5 mm and sandblasted before deposition. Microstructure of the milled nanocomposite powder and coating was observed using scanning electron microscope (SEM). Coating microhardness was tested using a Vickers microhardness indenter with a load of 300g and a dwell time of 15s.

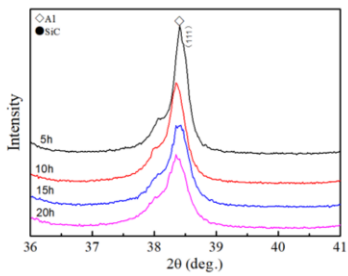
3. Results and Discussion

3.1. Characterization of Al-SiC Nanocomposite Powder

Figure 2 is the XRD patterns of Al-60SiC nanocompoiste powder, which was only consisted of Al and SiC two phases and no other phases such as oxidation were detected. In addition, Al (111) peak gradually decreased and its width increased with increasing milling time in figure 2(b). The FWHM (Full Width of Half Maxium) of Al (111) peak during milling process was calculated and shown in figure 3(a). For comparison, FWHM of initial Al powder was also added. It can be seen clearly that FWHM of Al (111) diffraction peak increased quickly from 0.12 to 0.21 rising by 75% after only 5 hrs milling and finally reached to 0.386 after milled for 20 hrs. It was well known that the broadening of diffraction peak is related with grain size reduction and mirostrain in lattice. Therefore, FWHM of Al (111) peak was used to quantitatively estimated grain size of Al matrix through the Scherrer formula. The results were shown in figure 3(b). It is clear that the grain size of Al decreased sharply at the initial stage (before 15 hrs) with increasing milling time and subsequently decreased slowly (after 15 hrs). After 5 hrs milling, the Al grain size rapidly decreased to 46 nm and reached a steady value of 22 nm after 20 hrs. This indicated that an Al-60SiC nanocomposite powder was fabricated by ball milling Al/SiC mixture powder for 20 hrs.

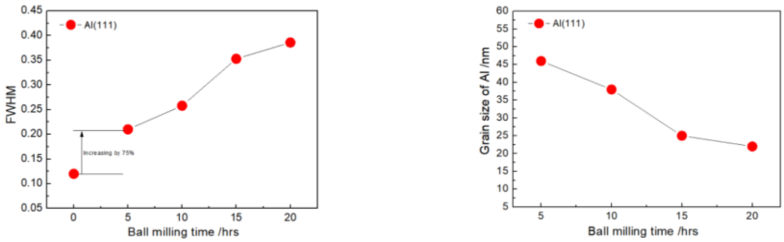


(a)



(b)

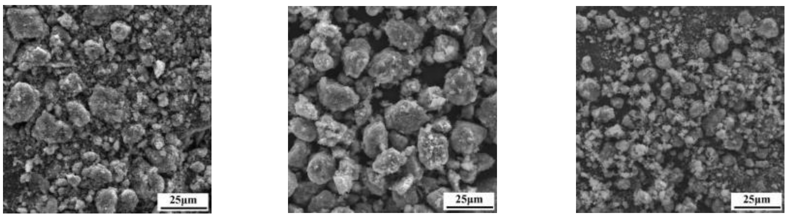
Figure 2. X-ray diffraction patterns of Al-60SiC nanocomposite powder at indicated milling times (a) and magnification of Al main peak (111) (b).



(a) (b)

Figure 3. FWHM (a) and grain size (b) of Al in Al-60SiC nanocomposite powder.

Figure 4 shows the SEM images of Al-60SiC$_p$ nanocomposite powders at different milling times. The powder milled for 5 hrs was angular shape (figure 4(a)) and powder size evidently increased but became homogeneous after milling 10 hrs (figure 4(b)). However, with increasing to 20 hrs, particle size significantly decreased (figure 4(c)). SiC particle like a micro-cutter because of its high hardness would cut soft Al particles into smaller ones during milling process. Simultaneously, initial soft Al particles would gradually become hard due to deformation and work hardening, and subsequently broken after experienced the plentiful repeated collisions. As a result, the particle size became smaller after milling for 20 hrs. Figure 5 shows the morphology and cross-section images of Al-60SiC$_p$ nanocomposite powders after milled for 20 hrs in high magnification. The milled powder exhibited a granular morphology with a size about 15 μm, which was suitable for cold spraying (figure 5(a)). SiC particles displayed homogeneous distribution in the nanocomposite powder (figure 5(b)). Hence, an Al matrix nanocomposite powder with high volume fraction of SiC particles can be prepared by ball milling.



(a) (b) (c)

Figure 4. SEM images of the Al-60SiC$_p$ nanocomposite powders after different milling times: 5 hrs (a), 10 hrs (b) and 20 hrs (c), respectively.

(a) (b)

Figure 5. Surface (a) and cross section (b) images of Al-60SiC$_p$ nanocomposite powders after milled for 20 hrs in high magnification.

3.2. Microstructure of Al-SiC Nanocomposite Coating

Microstructure of cold-sprayed Al-60SiC$_p$ nanocomposite coating are shown in figure 6. the conventional ‘‘splat’’ morphology of deposited particles can not be observed, indicating limited deformation of deposited particles, as shown in figures 6(a) and 6(b). In addition, many impact craters were evident, which resulted from the rebound-off particles that did not stick on. Despite the high content of the SiC phase and the great diffidence in plasticity of the Al and SiC, Al-60SiC$_p$ nanocomposite coating exhibited fully dense microstructure without noticeable pores and faultless interface as shown in figure 6(c), suggesting the good bonding between Al-60SiC$_p$ nanocomposite coating and the substrate. The dense microstructure of coating indicated that deposited particles wiht high velocity resulted from the driving gas had experienced intensive plastic deformation when impacting on substrate or deposited particles. In order to observe the SiC particles, the coating was etched by Krolls reagent (3ml HF: 6ml HNO_3: 100ml H_2O). It can be clearly seen that the nano SiC particles are uniformly distributed in the coating and maintained the angular morphology and size observed in the initial feedstock powder, as shown in figure 6(d).

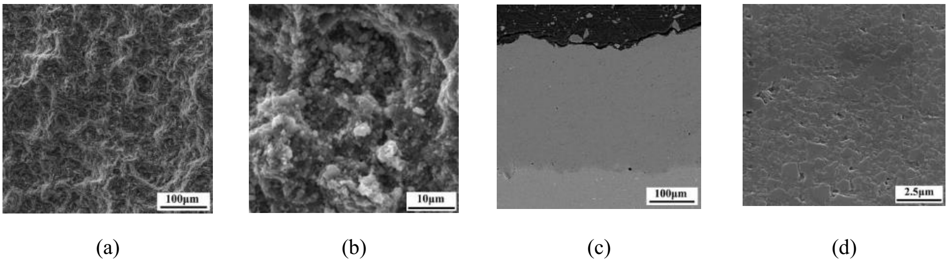


Figure 6. Surface (a, b) and cross section (c, d) images of cold-sprayed Al-60SiC$_p$ nanocomposite coating.

3.3. Microhardness of Al-SiC Nanocomposite Coating

Figure 7 shows microhardness of cold-sprayed Al-60SiC$_p$ nanocomposite coating and Al bulk. It can be seen that the microhardness of Al bulk was only 34±3 $Hv_{0.3}$, however, the microhardness of Al-60SiC$_p$ nanocomposite coating was far higher than that of Al bulk and reached up to 530±53 $Hv_{0.3}$, which was higher than that of the previous reports [9, 10]. High hardness of cold-sprayed Al-60SiC$_p$ nanocomposite coating would be attributed to three factors. The one was the high volume fraction of SiC particles, the second was refinement of Al matrix resulting from the ball milling and the third was the strain-hardening effect during cold spraying. Therefore, the cold-sprayed Al-60SiC$_p$ nanocomposite coating exhibited high mircrohardness under the integrated effects of above factors.

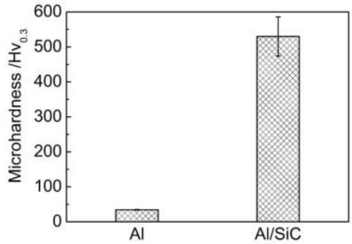


Figure 7. Hardness of cold-sprayed Al-60SiC_p nanocomposite coating.

4. Conclusions

Al-60SiC_p nanocomposite powder with morphology and size distribution suitable for cold spraying can be produced by ball milling. A dense Al-60SiC_p nanocomposite coating with SiC particles uniform distribution was successfully produced by cold spraying of the above powder and exhibited a high microhardnes about 530±53 Hv0.3

Acknowledgments

National Natural Science Foundation of China (NSFC) (No.51561013, 52161012) and Jiangxi Natural Science Foundation (No.20151BAB206008, 20192BAB206006) are acknowledged for the funding of the work.

References

[1] Eesley GL, Elmoursi A, Pater N. Thermal properties of kinetic spray Al-SiC metal matrix composite Mater. Res. 2013 Apr; 18(4): 855-60.
[2] Sansoucy E, Marcoux P, Ajdelsztajn L, Jodoin B. Properties of SiC-reinforced aluminum alloy coatings produced by the cold gas dynamic spraying process. Surf. Coat. Technol. 2008 May; 202(16) 3988-96.
[3] Davidson AM, Regener D. A comparison of aluminium-basedmetal-matrix composites reinforced with coated and uncoatedparticulate silicon carbide. Compos. Sci. Technol. 2000 May; 60(6):865-9.
[4] Yalcin Y, Akbulut H. Dry wear properties of A356-SiC particle reinforced MMCs produced by two melting routes. Mater. Design. 2006; 27(10): 872-81.
[5] Ray AK, Venkateswarlu K, Chaudhury SK, Das SK, Kumar BR, Pathak LC. Fabrication of TiN reinforced aluminium metal matrix composites through a powder metallurgical route. Mater. Sci. Eng. A. 2002 Dec; 338(1-2):160-5.
[6] Torres B, Campo M, Ureña A, Rams J. Thermal spray coatings of highly reinforced aluminium matrix composites with sol–gel silica coated SiC particles. Surf. Coat. Technol. 2007 May; 201(16):7552-9.
[7] Gui MC, Kang SB, Euh K. Thermal expansion behaviour of plasma sprayed Al–SiCp composites. Mater. Sci. Technol. 2008 Nov; 24(11):1362-8.
[8] Papyrin A. Cold spray technology. Adv. Mater. Process. 2001; 159(9):49-51.
[9] Van Steenkiste TH, Elmoursi A, Gorkiewicz D, Gillispie B. Fracture study of aluminum composite coatings produced by the kinetic spray method. Surf. Coat. Technol. 2005 Apr; 194(1):103-10.
[10] Li WY, Zhang G, Zhang C, Elkedim O, Liao H, Coddet C. Effect of ball milling of feedstock powder on microstructure and properties of TiN particle-reinforced Al Alloy-based composites fabricated by cold spraying. J. Therm. Spray Technol. 2008 Jun; 17(3): 316-22.
[11] Ajdelsztajn L, Jodoin B, Kim GE, Schoenung JM. Cold spray deposition of nanocrystalline aluminum alloys. Metall Mater Trans A. 2005 Mar; 36(11):657-66.
[12] Sherif El-Eskandarany M. Mechanical solid state mixing for synthesizing of SiCp/Al nanocomposites. J. Alloys Comp. 1998 Oct; 279 (2):263-71.