Effects of Cu-Coated SiC Content on Microstructure and Properties of Laser Cladding SiCp/Al–Si Composite Coatings

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Abstract: SiC particles (SiCp)-reinforced Al–Si matrix composite coatings were synthesized on 4032 aluminum alloy by laser cladding using powder mixtures of Al-20 wt.% Si alloy and electroless copper-plated SiC particles (SiCp-Cu). The effects of SiCp-Cu content on microstructure, phase composition, and microhardness of the SiCp/Al–Si laser cladding layer (LCL) were investigated systematically. The results showed that the microstructure of SiCp-Cu/Al–Si LCL was mainly composed of undissolved SiCp, lump-like primary Si, lump-like Al2Cu, plate-like Al4SiC4, and Al–Si–Cu ternary eutectic. In addition, the eutectic microstructure became finer with the increasing of SiCp-Cu content. The average microhardness of the LCL increased with the increasing of SiCp-Cu content. When SiCp-Cu content was 50 wt.%, the average microhardness of the LCL reached 508 HV0.05, which was about 3.5 times larger than that of the substrate. The LCL reinforced with a SiCp-Cu content of 30 wt.% exhibits the best wear resistance.

Keywords: laser cladding layer; laser processing; electroless copper; microhardness

1. Introduction

Aluminum alloys are extensively applied in the automotive industry and aircraft and other fields due to their reduced density, light weight, and high specific values of stiffness and strength. Nevertheless, the use of aluminum alloys for a wider range of application is limited due to their low surface hardness and poor wear resistance [1–4]. Therefore, it is necessary to improve surface properties and mechanical properties and prolong the service life of the parts made from aluminum alloys [5–7]. In order to improve surface properties of aluminum alloys, various attempts have been made, such as electroplating [8], electroless plating [9], thermal spraying [10], anodizing [11], and microarc oxidation [12]. However, the disadvantages of pollution of the environment and weak adhesion between the substrate and the coating still exist for these methods mentioned above, resulting in the difficulty of meeting the requirements under severe conditions. Compared with conventional surface treatment methods, the laser cladding process has the advantages of low clad dilution, rapid heating and cooling, small heat-affected zone, and good adaptability of surface properties [13–16].

Considerable research studies have been carried out to examine laser treatment of aluminum alloys. Sun et al. [17] fabricated composite coatings of Al–Si alloy reinforced with SiC particles on AlSi12 substrate; the microstructure and microhardness of the coatings were investigated, and the results showed that the coatings had much higher microhardness than that of the substrate, and the coatings were divided into two sublayers; the upper layer was composed of Al–Si eutectic, acicular primary Si, α-Al dendrites, and a little SiCp, while the bottom layer consisted of α-Al dendrites, Al–Si eutectic, and a large amount of SiCp. The oxidation effects during the laser treatment of aluminum coated
with SiCp/Al composite coating was studied by Hegge et al. [18], and the authors found that inert gas stream is not always enough to sufficiently prohibit contact between the air and the melt. Anandkumar et al. [19] studied the influence of the laser cladding process on the microstructure and abrasive wear resistance of SiCp/Al–Si composite coating; they observed that the microstructure and properties of the SiCp/Al–Si laser cladding layer (LCL) depends strongly on the processing parameters, especially power density and interaction time. The influence of addition of alloy elements on microstructure and microhardness of the SiCp/Al–Si LCL was investigated by Riquelme et al. [13]. The result indicated that the addition of Si or Ti particles to the composite coating is an effective method to avoid the formation of Al4C3. However, there is no research on the effect of electroless copper plating on SiCp on the properties of SiCp/Al–Si LCL.

In the process of laser cladding, SiCp tends to react with molten aluminum, leading to the formation of Al4C3 and Al4SiC4 and so on during solidification depending on temperature [20]. Between 667 °C and 1347 °C, reaction (1) takes place and produces Al4C3. When the temperature exceeds 1347 °C, reaction (2) takes place. When the temperature reaches 1927 °C, Al8SiC7 will be formed [21].

\[
\text{4Al(}l\text{) + }3\text{SiC} \rightarrow \text{Al}_4\text{C}_3 + 3\text{Si, (1)}
\]

\[
\text{4Al(}l\text{) + 4SiC} \rightarrow \text{Al}_4\text{SiC}_4 + 3\text{Si, (2)}
\]

The hardness of Al4SiC4 is as high as 1200 HV and its brittleness is low. In addition, it is chemically inert in humid environments, so Al4SiC4 is a favorable reinforcement phase [22,23]. In the process of preparing SiCp/Al–Si LCL, the Al4SiC4 phase is desired. The poor wettability between Al and SiCp will adversely reduce the reaction rate between Al and SiCp during the laser cladding process and the bonding strength between Al matrix and SiCp.

In this work, the wettability between SiCp and Al alloy is expected to be improved by electroless copper plating on the surface of SiCp. SiCp/Al–Si coatings have been deposited on 4032 aluminum alloy by the laser cladding process. The effects of the SiCp–Cu content on microstructure and properties of the LCL have been investigated for the first time. The purpose of this paper is to provide a technical way to improve surface properties of aluminum alloys.

2. Materials and Methods

2.1. Substrate and Cladding Material

The 4032 aluminum alloy was used as substrate for laser cladding with a dimension of 50 mm × 18 mm × 4 mm. The surface of the substrate was ground with abrasive paper and cleaned with alcohol before laser cladding.

The cladding material was a mechanical mixture of AlSi20 aluminum alloy and SiCp (including SiCp or SiCp–Cu) powders. The AlSi20 aluminum alloy powder used had a particle size of 50–100 µm and the SiCp had a particle size of 10–20 µm. The SiCp and AlSi20 powders were mixed in different compositions as shown in Table 1. The mixed powders were placed onto the surface of aluminum alloy with gum water as binders and dried at 80 °C for 6 h. The thickness of the precoated layer was approximately 0.5 mm.
Table 1. Composition ratio of laser cladding material.

| Number | SiC<sub>p-Cu</sub> (wt.%) | SiC<sub>p</sub> (wt.%) | Al (wt.%) |
|--------|---------------------------|-----------------------|-----------|
| 1      | 0                         | /                     | 100       |
| 2      | 10                        | /                     | 90        |
| 3      | 20                        | /                     | 80        |
| 4      | 30                        | /                     | 70        |
| 5      | 40                        | /                     | 60        |
| 6      | 50                        | /                     | 50        |
| 7      | /                         | 20                    | 80        |

2.2. Electroless Plating of SiC Particles

Before electroless plating, surface treatment was carried out on the SiC<sub>p</sub>. According to previous studies, pretreatment can be conducted by the traditional three-step method (coarsening, sensitization, and activation) [24,25]. After pretreatment mentioned above, electroless plating was conducted in a copper electroless bath. The composition and operating conditions of pretreatment solutions and electroless copper plating bath are displayed in Table 2. Lastly, the Cu-coated SiC<sub>p</sub> was washed with deionized water three times and dried under room temperature. Figure 1 shows the SEM images of SiC<sub>p</sub> and SiC<sub>p-Cu</sub>.

Table 2. Composition and operating conditions of pretreatment solutions and electroless copper plating bath.

| Roughening Solution | Sensitizing Solution | Activating Solution | Plating Bath |
|---------------------|----------------------|---------------------|--------------|
| HF (40%) 1.15 M     | /                    | /                   | /            |
| HCl (37%) /         | 1.20 M               | 0.24 M              | /            |
| SnCl<sub>2</sub> ∙ 2H<sub>2</sub>O / | 0.22 M | / | / |
| PdCl<sub>2</sub> / | /                    | 2.82 mM             | /            |
| CuSO<sub>4</sub> ∙ 5H<sub>2</sub>O / | / | / | 40 mM |
| NiSO<sub>4</sub> ∙ 6H<sub>2</sub>O / | / | / | 5.42 mM |
| NaH<sub>2</sub>PO<sub>4</sub> ∙ H<sub>2</sub>O / | / | / | 0.38 M |
| Na<sub>3</sub>Cr<sub>2</sub>H<sub>7</sub>O<sub>7</sub> ∙ 2H<sub>2</sub>O / | / | / | 0.14 M |
| H<sub>3</sub>BO<sub>3</sub> / | /                    | /                   | 0.48 M |
| T (°C) 25~30         | 25~30                | 25~30               | 65           |
| pH /                | /                    | /                   | 10.5         |
| t (min) 15           | 15                   | 15                  | 10           |

Figure 1. The SEM image of (a) uncoated SiC<sub>p</sub>, (b) SiC<sub>p-Cu</sub>.
2.3. Laser Cladding Experiment

Laser cladding was performed by using the CY-WL600G type Nd-YAG pulsed laser with a wavelength of 1.06 µm. Based on the systematic experiments done previously, the laser cladding process parameters used in this study were 800 W for laser beam power, 4 mm/s for laser scan speed, and 0.2 mm for laser beam diameter. There was a 50% overlap between two adjacent laser tracks. The thickness of LCLs obtained was about 0.45 mm. After laser processing, samples were cut for cross-section and polished with abrasive paper.

The microstructures of the LCL were analyzed by 10XB-PC optical microscope (OM) from Shanghai optical instrument factory and QUATA 250 FEG series field emission scanning electron microscope (SEM) from FEI. Semiquantitative analysis of element distribution was carried out by energy dispersive spectrometer (EDS), which was equipped with SEM. The LCL phase was tested by a DX2700 diffraction analysis system (XRD) from Shanghai Precision Instruments with Cu Kα radiation and XRD patterns were taken at 2θ angles from 15° to 85° at a scanning rate of 4°/min. Also, a BUEHLER5104 microhardness tester from German Buehler was used to obtain Vickers microhardness profiles along samples cross-section up to 750 µm using a load of 50 g for 10 s. For each sample, the microhardness measurements were repeated at five locations at the center and edges of the samples. The given average values of microhardness were average values taking from all measurement points on LCLs. Wear experiments were carried out using a PRN01-04882A pin-on-disk-type tribometer from Swiss CSM Company under dry-sliding conditions. The diameter of pin samples was 3 mm. The ring of the wear couple was made of diamond. The wear conditions were given as 1.4 MPa, 0.4 m·s⁻¹ sliding speed, and 250 m sliding distance. Wear was characterized using the mass loss of the samples and the observation of the wear scars.

3. Results and Discussion

3.1. Phase Analysis

The XRD patterns of SiCₚ-Cu/Al-Si coatings with different SiCₚ-Cu content are shown in Figure 2. As can be seen, in addition to Al and Si phases, great amounts of SiCₚ, Al₂Cu, Al₄Cu₉, Al₄SiC₄, and Al₄C₃ were found in the LCLs. The SiCₚ was the additive and Al₂Cu, Al₄Cu₉, Al₄SiC₄, and Al₄C₃ were in situ formed novel phases. Furthermore, with increasing SiCₚ-Cu content, more and more Al₂Cu, Al₄Cu₉, Al₄SiC₄, and Al₄C₃ compounds formed within the LCL and their diffraction peaks became obvious.

Table 3 describes the variation trend of 2θ values and intensities of Al peaks in LCLs with different SiCₚ-Cu content. At the same time, the 2θ values of the standard diffraction peak of Al are also listed. It can be seen that when the SiCₚ-Cu content is less than 50%, the 2θ values of Al diffraction peaks in the LCLs increase with increasing SiCₚ-Cu content, and all of them are larger than the standard 2θ values. When the SiCₚ-Cu content is 50 wt.%, the 2θ value of Al diffraction peak is smaller than the standard 2θ value. According to Bragg’s law [26], 2d sin θ = nλ (n = 1, 2, 3, …), the larger 2θ values indicate the smaller interplanar spacing of the corresponding crystal planes. It implies that the lattice deformation of the aluminum was caused by the high cooling rate and the huge residual stress during the laser cladding process.
without SiC is the Scherrer constant, \( K \) produced by laser cladding process was significantly refined. When the content of SiC increase with the increasing of thermal conductivity and the SiC the laser cladding process and possess fast solidification [27]. In addition, these solidification rates finer with increasing SiC p-Cu content in cladding materials. Meanwhile, the half high width of the XRD diffraction peaks in the LCLs increase with increasing SiCp-Cu content, and all of them are larger than standard 38.47 44.72.

### 3.2. Microstructural Analysis

As can be seen from Table 3, the intensity of XRD diffraction peaks of Al decreases with the increasing of SiCp-Cu content in cladding materials. Meanwhile, the half high width of the XRD diffraction peaks (FWHM) of Al increases. On the basis of the Scherrer formula [26], \( D = \frac{K\lambda}{B\cos\theta} \) (where \( K \) is the Scherrer constant, \( D \) is the average thickness of the grain perpendicular to the direction of the crystal plane, \( B \) is the half high width of the diffraction peak of the measured sample, \( \theta \) represents the diffraction angle, and \( \lambda \) is the X-ray wavelength), the increase of FWHM of Al indicates that the grain size of Al matrix decreased. It indicates that the crystal structure of the SiCp-Cu/Al-Si composite coating produced by laser cladding process was significantly refined. When the content of SiCp-Cu was 40 wt.%, the FWHM of Al was the largest, which means that the grain refinement was the most significant.

![Figure 2](image_url). XRD results of laser cladding layer with different SiCp-Cu content.

**Table 3.** Intensity variation of Al diffraction peak of laser cladding with different SiCp-Cu mass fraction.

| SiCp-Cu (wt.%) | \(\theta\) (°) | Intensity | FWHM  | \(\theta\) (°) | Intensity | FWHM  |
|---------------|---------------|-----------|-------|---------------|-----------|-------|
| standard      | 38.47         |           | 44.72 |               |           |       |
| 10            | 38.49         | 1080      | 0.240 | 44.77         | 1817      | 0.262 |
| 20            | 38.56         | 1027      | 0.250 | 44.81         | 1005      | 0.283 |
| 30            | 38.53         | 1134      | 0.262 | 44.76         | 1467      | 0.284 |
| 40            | 38.48         | 449       | 0.294 | 44.74         | 226       | 0.356 |
| 50            | 38.41         | 630       | 0.252 | 44.66         | 326       | 0.304 |

Figure 3 shows the SEM images of the cross-section of the LCLs with different SiCp-Cu content. SiCp-Cu with different sizes and shapes within the LCLs is observed. The SEM micrograph of the LCL without SiCp-Cu is shown in Figure 3a; it can be seen from the figure that the grain size is coarser than that in the coating reinforced with SiCp-Cu (Figure 3b–f). It can be seen from Figure 3a that there are cracks in the coating, and the existence of the cracks will have a negative impact on the properties of the coating. As seen in Figure 3b–f, the eutectic microstructures of the laser cladding layer become finer with increasing SiCp-Cu content due to the LCLs absorbing rapid heating and cooling during the laser cladding process and possess fast solidification [27]. In addition, these solidification rates increase with the increasing of thermal conductivity and the SiCp-Cu content, and as a result, thermal
The conductivity of SiC (259 Wm$^{-1}$K$^{-1}$) [28] and copper (401 Wm$^{-1}$K$^{-1}$) is higher than that of aluminum (237 Wm$^{-1}$K$^{-1}$) [29].

Figure 3. SEM images of laser cladding layer with different content of SiC$_{p}$-Cu (a) 0 wt.%; (b) 10 wt.%; (c) 20 wt.%; (d) 30 wt.%; (e) 40 wt.%; (f) 50 wt.%.

The SEM micrographs of LCL with 20 wt.% of SiC$_{p}$-Cu and 20 wt.% of SiC$_{p}$ are demonstrated in Figures 3c and 4, respectively. The SiC$_{p}$ remained almost unmelted and was still in an irregular polygonal shape as is shown in Figure 4. Conversely, the most SiC$_{p}$-Cu was oval-shaped and had a smaller size than that of the SiC$_{p}$-Cu originally used. It is indicated that the wettability of aluminum melt and SiC$_{p}$ can be improved by electroless copper plating process. SiC$_{p}$-Cu is more likely to react with molten aluminum during the laser cladding process. It can be seen from Figure 3 that some SiC$_{p}$ were also in an irregular polygonal shape. This is because not all SiC$_{p}$ were coated entirely with copper during electroless plating as shown in Figure 1.
The microstructure of the LCL with SiC_{p-Cu} content of 50 wt.% at a higher magnification is shown in Figure 5. It is clear that the microstructure of the LCL was mainly composed of undissolved SiC_{p} and dark gray lump-like crystals which were distributed on the ternary eutectic of Al–Si–Cu.

![Figure 4. SEM images of a laser cladding layer with a SiC_{p} content of 20 wt.%](image)

The Si content of AlSi20 alloy powders used in cladding materials is 20 wt.%. At the same time, SiC_{p-Cu} reacts with molten aluminum and forms Al_{4}SiC_{4} and Si during the laser cladding process. The Si is dissolved in AlSi20, increasing its Si percentage, so that the content of Si in the molten aluminum could exceed the eutectic point. On the basis of the Al–Si binary phase diagram, the hypereutectic Al–Si matrix microstructure consisted of Al–Si eutectic and acicular primary Si crystals [17].

After electroless copper plating of SiC_{p}, the weight gain percentage of SiC_{p} is close to 100%, so the cladding material with SiC_{p-Cu} content of 50 wt.% is comprised of 50 wt.% of Al–Si powder, 25 wt.% of SiC_{p}, and 25 wt.% of Cu. The Al–Cu–Si ternary eutectic alloy is mainly composed of primary crystal Si, Al + Al_{2}Cu binary eutectic, and Al + Si + Al_{2}Cu ternary eutectic composition due to the high cooling rate (in the range of 10^{3}–10^{8} K/s during the laser cladding process) [30–32].

EDS analysis was performed to examine the exact composition of LCL with SiC_{p-Cu} content of 50 wt.%. Results of EDS analysis conducted on points a–d in Figure 6 are then summarized in Table 4. Combining with the XRD phase analysis (Figure 2), it was reasonable to consider that the white lump-like crystals (point b) were Al_{2}Cu, the black plate-like crystals (point c) were Al_{4}SiC_{4}, and the light gray region (point d) was Al + Al_{2}Cu binary eutectic. The dark gray lump-like crystals (point a) in Figure 6 may be Si. Figure 7a shows the SEM image of the laser cladding layer. Figure 7b–d show the elemental maps of the LCL corresponding to the distribution of Al, Si, and C, respectively. According to that, the dark gray lump-like crystals (point a) in Figure 6 and acicular crystals can be recognized as Si phase. In summary, the microstructure of SiC_{p-Cu}/Al–Si LCL mainly comprises undissolved SiC_{p}, lump-like primary Si, lump-like Al_{2}Cu, plate-like Al_{4}SiC_{4}, and Al–Si–Cu ternary eutectic.

![Figure 5. Microstructures of a laser cladding layer with a SiC_{p-Cu} content of 50 wt.%](image)
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Table 4. EDS analysis of laser cladding layer with a SiC$_p$-Cu content of 50 wt.% (corresponding to a, b, c, d points in Figure 6).

| Detection Positions | Al (wt.%) | Si (wt.%) | C (wt.%) | Cu (wt.%) |
|---------------------|-----------|-----------|----------|-----------|
| a                   | 26.03     | 50.01     | 2.40     | 21.56     |
| b                   | 45.01     | 10.80     | 3.87     | 40.32     |
| c                   | 32.30     | 11.15     | 36.94    | 20.62     |
| d                   | 55.74     | 4.09      | 2.37     | 37.81     |

Figure 6. Microstructure of a laser cladding layer with a SiC$_p$-Cu content of 50 wt.%.

Figure 7. Distribution of aluminium (b), silicon (c), and carbon (d) of microstructure of the laser cladding layer with a SiC$_p$-Cu content of 50 wt.% (a).

Figure 8 shows the interface between the LCL and the substrate. (The samples were cut perpendicular to the LCL direction and polished. The images were taken in the center of the LCL region.) OM images of the coating before etching are presented in Figure 8a. The curved edges of
the interface between the coating and the substrate caused by the laser beam center had a higher temperature than that of the edge region. After etching the surface of the LCL using the Keller’s reagent, the OM images obtained are shown in Figure 8b. It can be seen that there are many orientated growth dendrites between the substrate and the coating, and the growth direction is substantially perpendicular to the substrate. Moreover, the LCLs show good metallurgical bonding to the substrate due to the orientated growth dendrites which are intergrown with the substrate.

![Figure 8](image_url). Interface morphologies of SiC_p-Cu/Al–Si laser cladding before etching (a) and after etching (b).

### 3.3. Microhardness

Figure 9 shows the relationship between microhardness of LCLs measured on the cross-section and the SiC_p-Cu content in cladding materials. It can be seen that the average microhardness increases with the increasing SiC_p-Cu content. It is noteworthy that the average microhardness of the LCL with SiC_p-Cu content of 50 wt.% (508 HV_{0.05}) is about 3.5 times higher than in the 4032 aluminum alloy substrate (145 HV_{0.05}).

![Figure 9](image_url). Relationship between microhardness and the SiC_p-Cu content.

The variation of microhardness along depth direction of the LCLs is shown in Figure 10. As can be seen, the microhardness of LCL reinforced with SiC_p-Cu ranges from 190 HV_{0.05} to 250 HV_{0.05}, and the average value is 210 HV_{0.05}. The microhardness of the other LCL reinforced with SiC_p is between 170 and 209 HV_{0.05} and the average value is 192 HV_{0.05}. This indicates that electroless copper plating on SiC_p can improve the microhardness of SiC_p/Al–Si composite coating.
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The two reasons for the high microhardness of the SiCp/Al–Si composite coating are as follows: Firstly, the increase in microhardness is mainly attributed to the dissolution of SiCp-Cu in the LCLs and the resulting increase in the numbers of Al4SiC4 (1200 HV [30]) and Al–Cu intermetallic (microhardness of Al2Cu in the range of 400–600 HV0.2 [33]) formed on resolidification. Secondly, the effects of laser rapid heating and cooling cause a finer and harder microstructure.

3.4. Wear Properties

The wear mass loss of all samples is presented in Figure 11. It can be seen that the wear mass loss showed a decrease as the content of SiCp-Cu increased from 0 to 30 wt.% and was less than that of the substrate. On the contrary, the LCLs with 40–50 wt.% of SiCp-Cu had more wear mass loss compared with the substrate. The wear mass loss of LCL with a SiCp content of 20 wt.% was less than that of the substrate, but more than that of the LCL with a SiCp-Cu content of 20 wt.%. Figure 12 shows the SEM images of the worn surface of all samples. In Figure 12a, it is clearly observed that the worn surface of the substrate was easily deformed plastically under stress and shows parallel grooves. The grooves on the worn surface of the LCLs became narrower and shallower as the content of SiCp-Cu increased from 0 to 30 wt.%, as shown in Figure 12b–e. The grooves on the worn surface of the LCL with 20 wt.% of SiCp were deeper and wider compared with those of the LCL with 20 wt.% of SiCp-Cu. Nevertheless, it can be seen from Figure 12f–g that the grooves became deeper as the content of SiCp-Cu increased from 40 to 50 wt.%. Therefore, the LCL with 30 wt.% of SiCp-Cu exhibits the best wear resistance, and electroless copper plating on SiCp can improve the wear resistance of SiCp/Al–Si composite coating. Improvement of wear resistance of the SiCp/Al–Si composite coating must be attributed to the presence of Al4SiC4 and Al–Cu intermetallic and finer microstructure. When the content of SiCp-Cu reaches 40 wt.% or more, the content of AlSi20 decreases evidently, resulting in the difficulty of SiCp-Cu packed by Al–Si alloy. The SiCp-Cu were easily separated from the worn surface during the wear test and tended to plow the LCLs seriously. Consequently, the decrease of the wear resistance of the LCLs with high SiCp-Cu content is observed.
The wear mass loss of all samples is presented in Figure 11. It can be seen that the wear mass loss showed a decrease as the content of SiCp-Cu increased from 0 to 30 wt.% and was less than that of the substrate. On the contrary, the LCLs with 40–50 wt.% of SiCp-Cu had more wear mass loss compared with those of the LCL with a SiCp content of 20 wt.%. Nevertheless, it can be seen from Figure 12f–g that the grooves became deeper as the content of SiCp-Cu increased from 40 to 50 wt.%. Therefore, the LCL with 30 wt.% of SiCp-Cu exhibits the best wear resistance, and electroless copper plating on SiCp can improve the properties of SiCp/Al–Si composite coatings.

Figure 11. Wear mass loss of all samples.

Figure 12. The worn surface morphologies of the substrate and laser cladding coatings with the different SiCp contents; (a) substrate; (b) 100% AlSi20; (c) 10 wt.% SiCp-Cu + 90 wt.% AlSi20; (d) 20 wt.% SiCp-Cu + 80 wt.% AlSi20; (e) 30 wt.% SiCp-Cu + 70 wt.% AlSi20; (f) 40 wt.% SiCp-Cu + 60 wt.% AlSi20; (g) 50 wt.% SiCp-Cu + 50 wt.% AlSi20; (h) 20 wt.% SiCp + 80 wt.% AlSi20.
4. Conclusions

1) SiC\textsubscript{p}-reinforced aluminum matrix composite coatings with high microhardness can be successfully obtained on the surface of 4032 aluminum alloy by the laser cladding process. Electroless copper plating on SiC\textsubscript{p} can improve the properties of SiC\textsubscript{p}/Al–Si composite coating.

2) The microstructure of the SiC\textsubscript{p-Cu}/Al–Si laser cladding layer consisted of undissolved SiC\textsubscript{p}, lump-like primary Si, lump-like Al\textsubscript{2}Cu, plate-like Al\textsubscript{4}SiC\textsubscript{4}, and Al–Si–Cu ternary eutectic. Meanwhile, the microstructure became finer with the increasing of SiC\textsubscript{p-Cu} content due to the fast solidification.

3) The microhardness of the laser cladding layer increased with the increasing of SiC\textsubscript{p-Cu} content. It increased from 145 HV\textsubscript{0.05} to 508 HV\textsubscript{0.05} due to the presence of Al\textsubscript{4}SiC\textsubscript{4} and Al–Cu intermetallic and finer microstructure.

4) The wear resistance of the laser cladding layer increased with the increasing of SiC\textsubscript{p-Cu} content. The LCL reinforced with a SiC\textsubscript{p-Cu} content of 30 wt.% exhibits the best wear resistance. When the SiC\textsubscript{p-Cu} content reached 40-50 wt.%, the wear resistance of the LCLs decreased due to the spalling of SiC\textsubscript{p-Cu} during the wear test.

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