Review Paper on Effect of WC-Ni Content on Wear Behavior of Laser clad Ni- based alloys

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ABSTRACT

A review on Ni-based composite coatings produced on the Ti6Al4V substrate by laser cladding by varying the percentage of clad materials was done. Accordingly it was observed that as the percentage of NiCrBSi was varied, the average micro hardness of the coatings went on increasing. It has been found that the micro hardness and wear resistance of the Ni-based alloy coatings are greatly increased after adding the WC–Ni particles, due to the formation of hard WC phase and a partial dissolution of WC particles on the Ni matrix after laser cladding. It was observed that as the contents of NiCrBSi were varied (0 wt.%, 49 wt.%, 63 wt.%, 70 wt.%), the average microhardness of the coatings was increased gradually (745 HV0.1, 976 HV0.1, 1046 HV0.1 and 1107 HV0.1), however fracture toughness presents the opposite change trend (4.20 MPa m1/2, 3.57 MPa m1/2, 3.02 MPa m1/2 and 2.92 MPa m1/2). Wear mechanism was also changed from the micro-cutting into the mixture of the micro-cutting and the brittle debonding, into the brittle debonding. The appropriate addition of Ni (21 wt.%) into the 30 wt.%WC-NiCrBSi cladding material was favorable to the improvement in wear resistance of the coating. Also a review on the comparative study of the structure and wear resistance of NiCrBSi/50 wt.% WC composite coatings by laser cladding and laser induction hybrid cladding. In the review it was found out that Under the same laser processing parameters, the cladding height during LC was much higher than that during LIHC, whereas the dilution, cladding width, heat-affected-zone (HAZ) and efficiency of powder utilization during Laser Cladding were much smaller than those during Laser Induction Hybrid Cladding. the increase of the laser scanning speed during LIHC decreased the heat damage of WC particles, improved the homogenous distribution of WC particles and further increased the microhardness of the binder metal, which in turn led to an increase in the wear resistance of the composite coating.

Keywords*: laser cladding, microhardness, wear resistance, laser hybrid cladding.*

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1. Introduction

Laser cladding by powder injection has received significant attention in recent years due to its unique features and capabilities in various industries involved in metallic coating, high-value components repair, prototyping, and low-volume manufacturing. It is a manufacturing process to generate a dense and metallurgical bonded coating over a substrate. This protective coating can increase the machinery lifespan by preventing components from severe wear and corrosion.

As one of excellent surface modification technologies, laser cladding is widely employed for deposition of a protective layer on a surface of a cheaper or low-property material [1]. This protective coating can increase the machinery lifespan by preventing components from severe wear and corrosion [2].Ceramic-metal composite coatings with combined properties of high hardness, high wear resistance, good corrosion resistance and high toughness are often produced by electroplating [3,4], thermal spraying [5-7] and TIG-welding [8] on conventional substrate materials to improve their surface properties. Generally, the electroplating technique has a low cost, but the ceramic-metal composite coatings applied by this method show poor bonding to the substrate, resulting in decrease service life. Additionally, the electroplating technique counters difficulty in increasing the content of ceramic phases in the ceramicmetal composite coatings, and the wear resistance of these coatings requires further improvement [9]. Although thermal spraying has a high efficiency, the ceramic-metal composite coatings produced by this mature technique exhibit mechanical bonding to the substrate, resulting in easy spalling of the composite coatings in the course of service. In addition, the ceramic phases with high hardness were easily decomposed during thermal spraying, leading to degradation of the properties of the ceramic coatings [10]. The TIG-welding technique can improve the processing efficiency and produce the ceramic-metal composite coatings with a metallurgical bonding to the substrate. However, due to the high energy input of TIG-welding, the dilution of the composite coatings was relatively high, the substrate was susceptible to deformation, and the ceramic phases were easily decomposed [11].

As an advanced surface modification technique, laser cladding was used to produce ceramic-metal composite coatings that have low dilution, a dense microstructure, metallurgical bonding to the substrate, high wear resistance and high corrosion resistance, and this technique has received significant attention in recent years [12–15].Two main methods were used to produce ceramic-metal composite coatings: Laser Cladding and Laser Induction Hybrid Cladding

Rong et al. investigated microstructure and mechanical properties of laser cladding WC reinforced Ni-based alloy coating, and the results indicated that the hardness of Ni-based coating was increased with the increase in WC contents. [16]

Guo et al.' study also showed that the Ni-based coating with the addition of WC particles exhibited more excellent wear resistance than that without the addition of WC.[17]

In addition, Xu et al. studied the tensile properties of laser cladded WC/Ni composite coatings with different contents of WC particle. It was found that the tensile property of the coating was decreased with the increase in content of WC particles and the moderate WC contents reduced the number of cracks.[18]

Guo et al. had also studied the effects of the WC–Ni contents on the Ni-based coating prepared by laser cladding. The results indicated that the laser cladding coatings are free of cracks and almost no pores when the content of WC–Ni did not exceed 35 wt %.The mentioned studies showed that the addition of WC to Ni-based coatings can result in an improvement in microstructure and hardness, wear performance and tensile properties.

In the present work, the mixture powders of 30 wt % WC particle and 7 wt. (Ni–NiCrBSi) alloy powder were used to produce the Ni-based composite coatings by laser cladding. The relative contents of Ni and NiCrBSi were changed as following: 70 wt.% Ni–0 wt.% NiCrBSi, 21 wt.% Ni–49 wt.% NiCrBSi, 7 wt.% Ni–63 wt.% NiCrBSi, 0 wt.% Ni–70 wt.% NiCrBSi. The microstructural evolution of the coatings with different contents of NiCrBSi was investigated.

2. Literature Review

In this study, pure Ni, WC powder and NiCrBSi alloy powder (F102) with the nominal composition of Cr-16, B-4, Si-4 and Ni-balance (wt %) were used as the cladding material. The morphologies of these powders are illustrated in Fig-1. The used cladding materials are shown in Table-1, and the coatings are named from No. 1 to 4. Prior to laser cladding, the mixed powders were pre-placed onto the substrate surface with a binder (4% polyvinyl alcohol), and a layer with a thickness of approximately 1 mm was formed for the subsequent laser cladding.[19]

After laser cladding, the samples were cut perpendicularly to the laser scanning direction using an electro-spark cutting machine. The metallographic specimens were prepared using a Buehler Phoenix 4000 sample preparation system and etched with a mixed solution consisting of 5 ml H2O, 4 ml HNO3 and 1 ml HF. Microstructure was characterized by using an X-ray diffractometer (XRD) with Cu Ka radiation (k = 0.154060 nm), a VHX-600K optical microscope (OM) and a JSJM6460 scanning electron microscope (SEM) coupled with energy dispersive spectrometer (EDS). Micro-hardness distribution across the whole coatings was carried out on a HXD-1000TM micro-hardness tester with an applied load of 100 g for 15 s.[19]

Cracking susceptibility of the coatings was assessed in terms of fracture toughness (KIC). KIC was measured using the Vickers indentation method. The indentations were made on the cross sections of the coatings with an applied load of 30 N for 20 s using a Vickers-hardness tester (HV-120), and morphologies of the indentations were observed immediately using OM. Figure-2 shows the schematic diagram of the KIC test, and KIC of the coating was calculated by the following equation:

$$K_{IC} = 0.079\left(\frac{P}{a^\wedge(\frac{3}{2})}\right)\log\left(4.5\frac{a}{c}\right) \quad for\ 0.6 \le \frac{c}{a} \le 4.5 \qquad (19)$$

Where KIC is fracture toughness (MPa m1/2), P is the applied load (N), a is half the length of a diagonal line in an indentation (m), and c is half the length of a diagonal plus half the length of crack (m).[19]

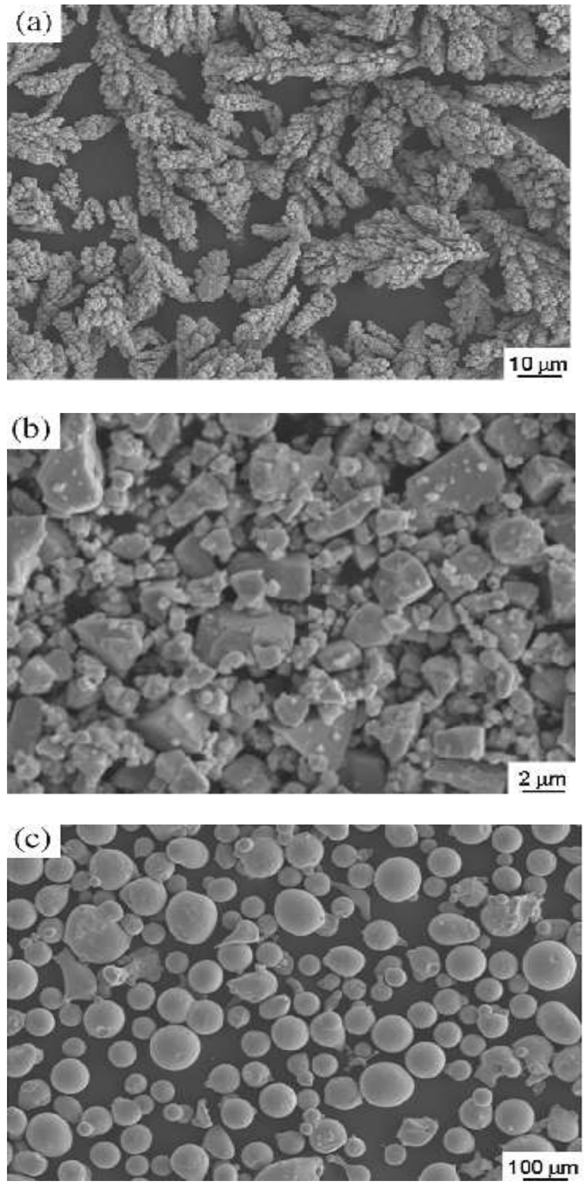

Figure-1: Morphologies of the initial powders:(a)Ni powder,(b)WC powder and (c)NiCrBSi alloy powder (19)

Table-1
The coatings prepared with different materials

Coatings	Cladding materials (in wt.%)
1	30%WC–70% Ni–0% NiCrBSi
2	30%WC–21% Ni–49% NiCrBSi
3	30%WC–7% Ni–63% NiCrBSi
4	30%WC–0% Ni–70% NiCrBSi

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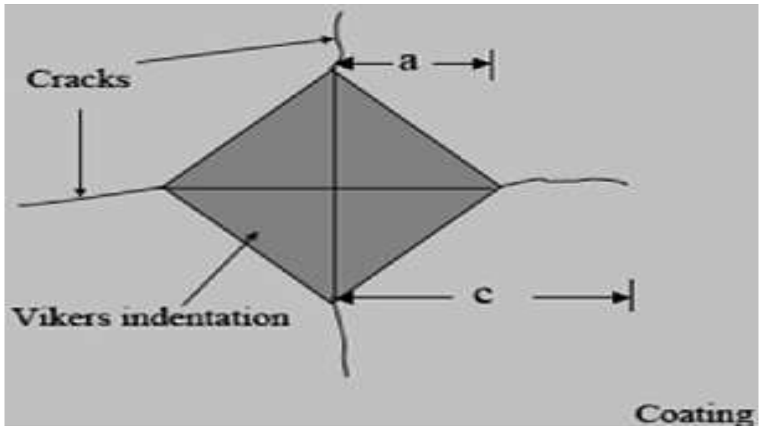

Figure-2: The schematic diagram of the fracture toughness (KIC) test. (19)

2.1 Micro-structural Analysis:

The macro-morphologies of the coatings are seen in the figure-3. It is found that the surfaces of the coatings before and after the addition of NiCrBSi present different morphologies. The surface of the coating 1 without the addition of NiCrBSi is smooth and nearly paralleled to the surface of the substrate while the surfaces of the coatings (2, 3 and 4) with different contents of NiCrBSi present the arc-convex shape, which should be originated from the change in chemical composition of the cladding powder. It is known that the molten pool with different chemical compositions has different surface tension coefficient{[19]

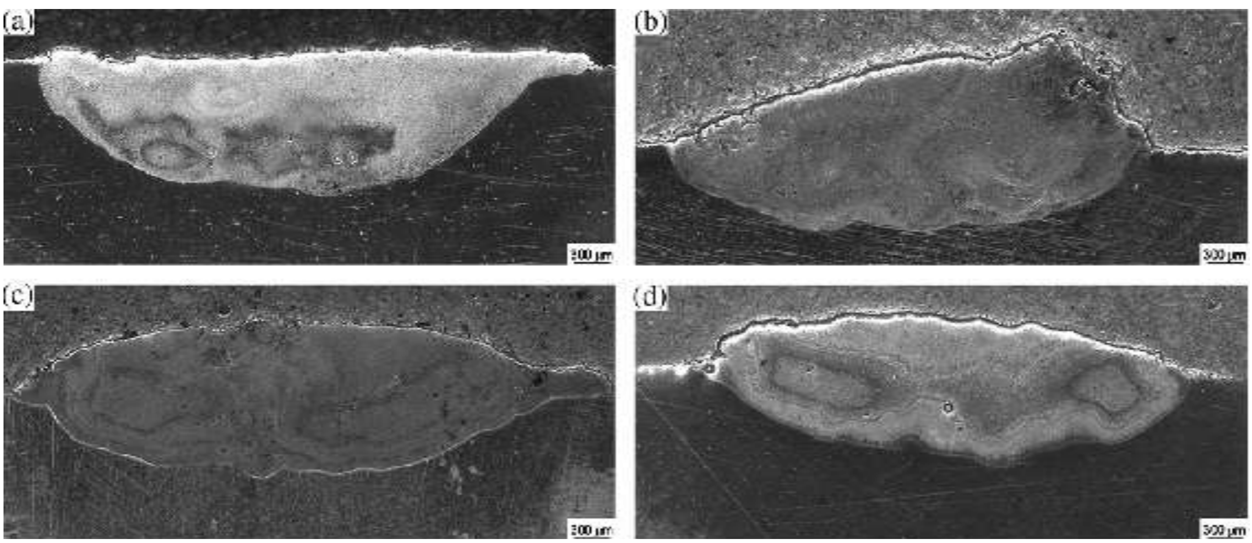

Figure-3: Macro-morphologies of the coatings. (19).

2.2Micro-hardness:

The average hardness of the coatings shows an increased trend with the increase in content of NiCrBSi in the cladding material. It was noted that the addition of NiCrBSi contributes to the improvement of micro-hardness. Figure -4 shows the micro-hardness profiles along the depth of the coatings with the different Ni–NiCrBSi contents.[19]

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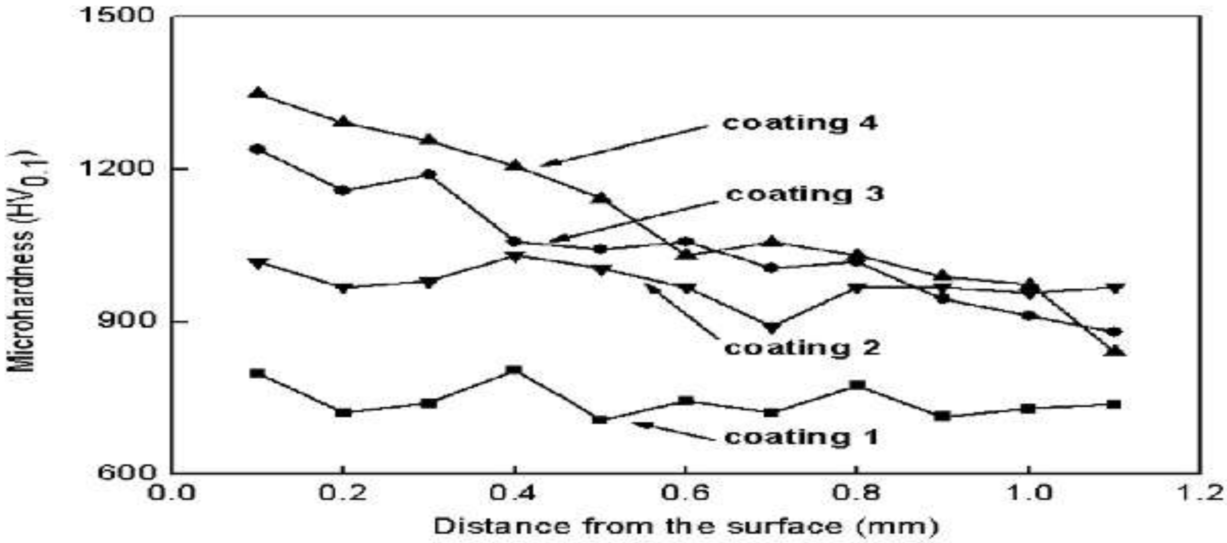

Figure-4: Micro-hardness profiles along the depth of the coatings with the different Ni–NiCrBSi contents. (19)

2.3 Fracture Toughness:

Fracture toughness of the coatings was measured using the Vickers indentation method, which was an index to assess the cracking susceptibility. The indentations were prepared in the representative areas of the coatings under the different content of Ni–NiCrBSi. As seen in Figure-5, indentations and cracks are clear, and cracks generated at the corners of the indentations and propagated outward. Fracture toughness of the coatings is about 4.20, 3.57, 3.02 and 2.92 MPa m1/2. Fracture toughness of the coating 2 with the addition of NiCrBSi is decreased by about 15% compared with that of the coating 1 without the addition of NiCrBSi, which means that the addition of NiCrBSi can increase the cracking susceptibility of the coatings to a certain extent. In addition, the values of the fracture toughness in the coating 3 and 4 are approximately equal due to the similar chemical compositions about 30%WC-7%Ni-63%NiCrBSi and 30%WC-0%Ni-70%NiCrBSi in the cladding materials. It is easily found that the fracture toughness of the coatings present the decreased trend whereas the change in the average micro-hardness of the coatings is increased gradually with the increase in content of NiCrBSi.[19].

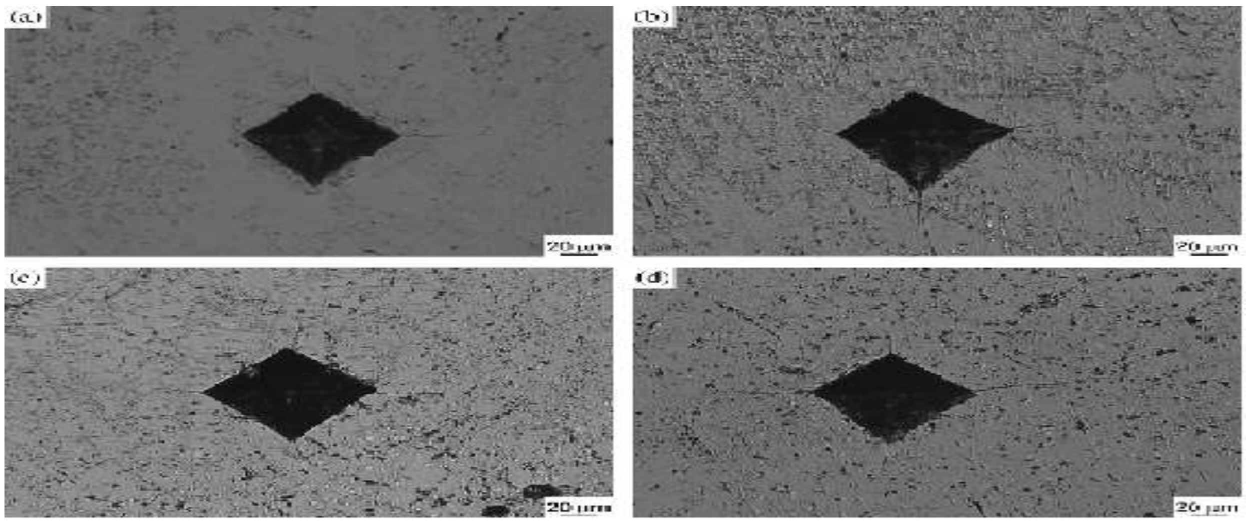

Figure-5: morphologies of the indentations in the representative areas of the coatings with the different content of Ni–NiCrBSi.(19)

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2.4 Wear Resistance:

Dry sliding friction and wear tests were carried out to investigate wear resistance of the coatings. Figure-6 shows the worn surface of the coatings with the different content of NiCrBSi. Some furrows and bulges are observed on the worn surface of the coating 1 without the addition of NiCrBSi (see Figure-6a). It indicates that the main wear mechanism of the coating 1 is the micro-cutting wear. Compared with the above, it is also found that some lamellar patterns and slight scars are presented on the worn surface of the coating 2 with the addition of NiCrBSi (see Figure6b). The wear process should be governed jointly by the micro-cutting and the brittle debonding.[19]

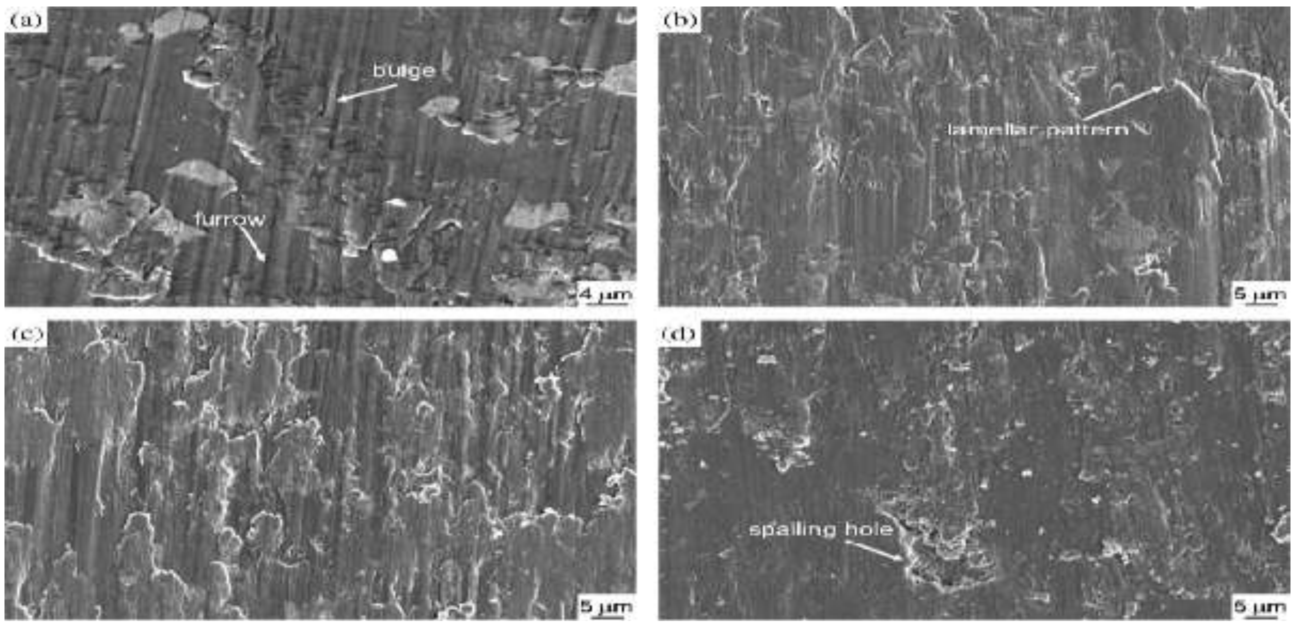


Figure-6: images of the worn surfaces of the coatings with the different content of Ni–NiCrBSi.(19)

When the content of NiCrBSi is further increased to 63%, the worn surface morphology of the coating 3 is very similar to that of the coating 2. For the coating 4 without the Ni addition, the worn surface becomes comparatively smooth. Some brittle debonding patterns were also found. The wear mechanism was mainly the brittle debonding. As the content of NiCrBSi in the cladding material rises, micro-hardness of the coatings is increased gradually while the fracture toughness has the opposite trend. The increase in micro-hardness can improve the resistance to micro-cutting of the coating; however, the reduction in fracture toughness can increase the cracking susceptibility and further promote the brittle debonding of the coating. The corresponding schematic diagram of the wear morphologies and wear mechanism of the coatings under the different Ni– NiCrBSi contents is shown in Figure-7. Figure-8 shows the wear profiles of the coatings after dry sliding wear test and the corresponding results are listed in Table-2. It is seen that the coating 1 without the addition of NiCrBSi has a huger profile with a wear volume of 2.4113 mm3 and the corresponding wear scar width and depth are larger than that (0.7596, 0.9709 and 0.2185 mm3) of the coatings (2, 3 and 4) with the addition of NiCrBSi. Compared with wear volume of the coating 1, the wear volume of the coatings is decreased by 68.5%, 59.7% and 90.9%, respectively. Therefore, it is indicated that the increase in the content of NiCrBSi in the cladding material can reduce the wear volume in a wear test of 30 min duration. Based on the above analysis, it is inferred that the wear performance of the coating may be improved by adding the appropriate content of Ni (21%) into the 30%WC-NiCrBSi cladding material. The wear rates of the NiCrBSi and NiCrBSi/WC–Ni coatings are shown in figure-9.[19]

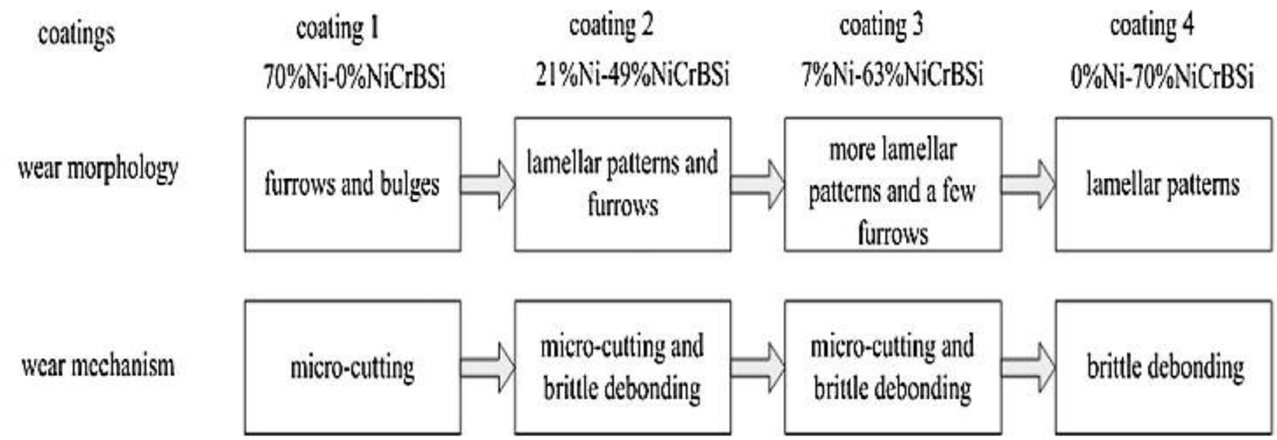


Figure-7: The schematic diagram of the wear morphology and wear mechanism of the coatings under the different Ni–NiCrBSi contents. (19)

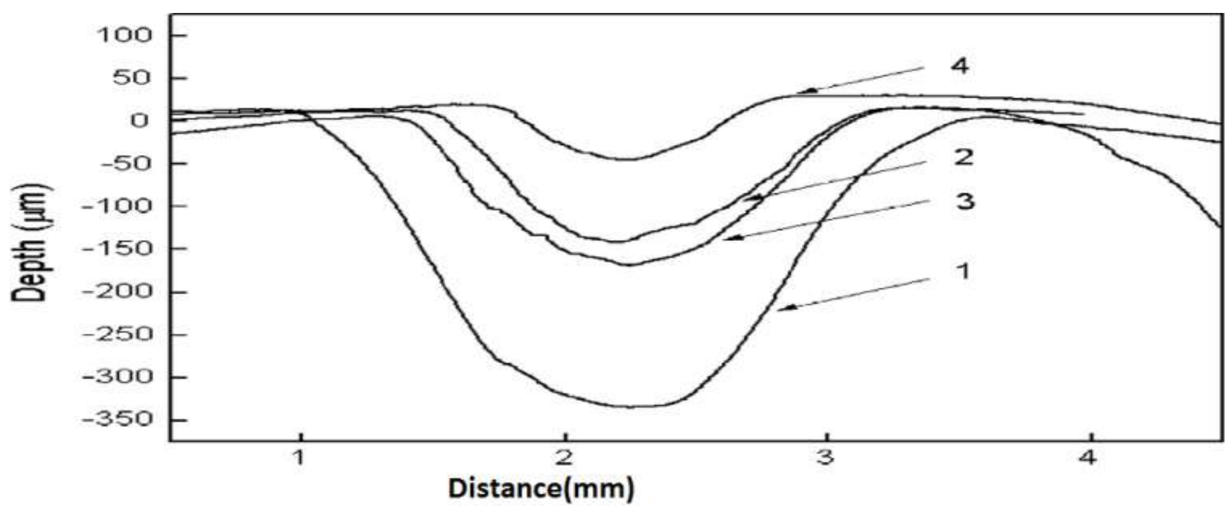


Figure-8: Wear profiles of the coatings after dry sliding wear tests. (19)

Table-2: Sliding wear results for the coatings[19]

Samples	Wear width (mm)	Wear depth (lm)	Wear volume (mm3)
Coating 1	2.6999	343.10	2.4113
Coating 2	1.8844	154.77	0.7596
Coating 3	1.9981	178.33	0.9709
Coating 4	1.2029	108.33	0.2185

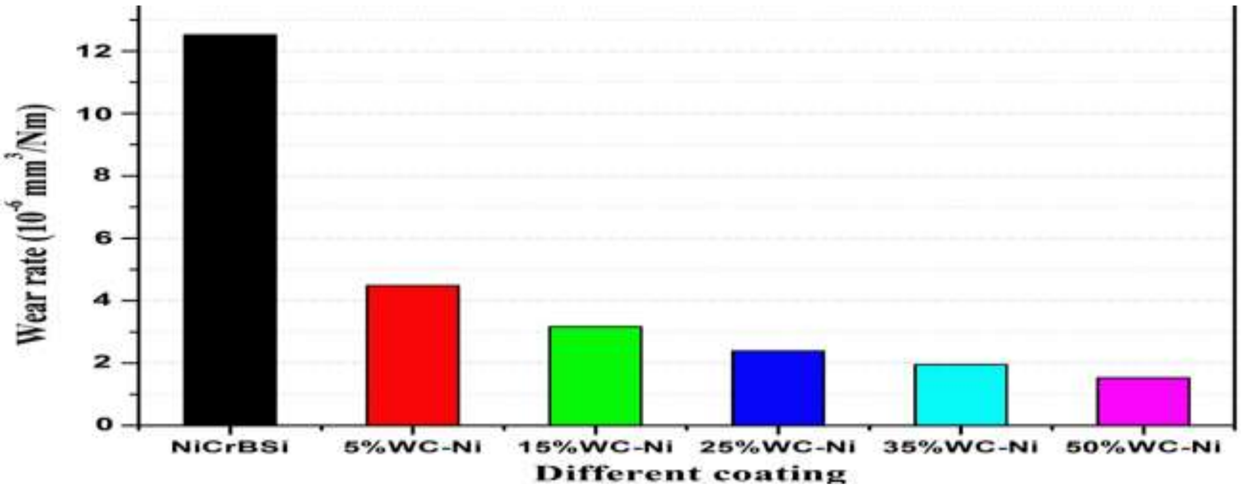
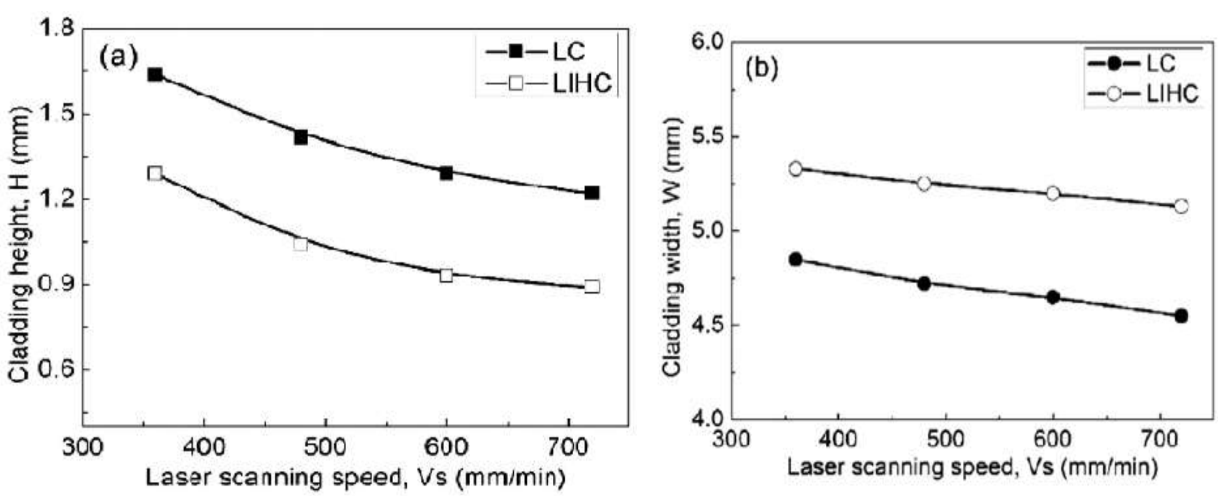


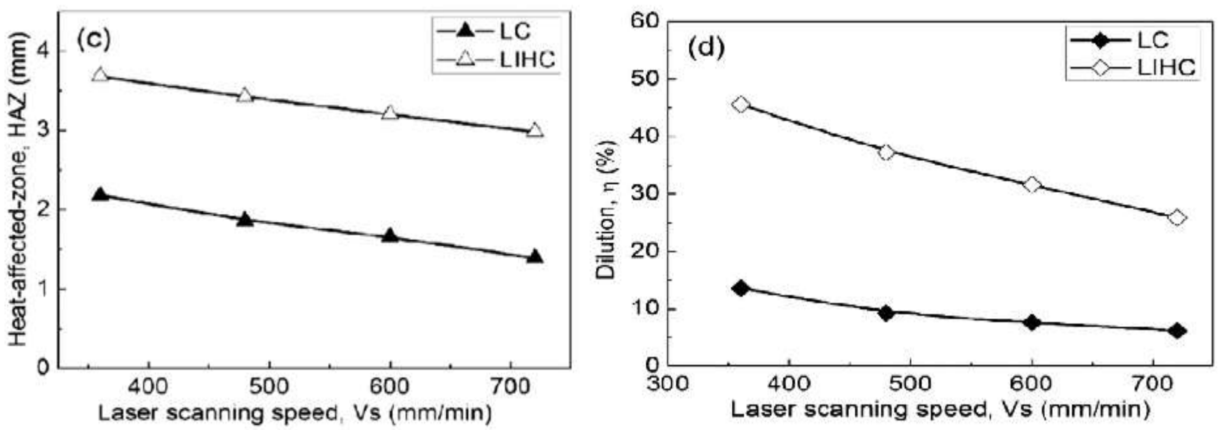
Figure-9: Wear rates of the NiCrBSi and NiCrBSi/WC–Ni composite coatings.

Recently**, laser induction hybrid cladding (LIHC)** was developed, and this method produces crack-free Ni-based WC composite coatings with an efficiency four times higher than that of individual laser cladding.
NiCrBSi/50 wt.% WC composite coatings were produced on carbon steel via laser cladding (LC) and laser induction hybrid cladding (LIHC).
Under the same laser processing parameters, the cladding height during LC was much higher than that during LIHC, whereas the dilution, cladding width, heat-affected-zone (HAZ) and efficiency of powder utilization during LC were much smaller than those during LIHC.[20]
A medium carbon steel plate (0.45 wt.% C) with dimensions of 120mm× 80mm× 8mmwas used as the substrate and was thoroughly ground and cleaned with acetone prior to LC and LIHC.[20]
An Ni-based alloy powder with an average size of 90 µm was used as the binder metal, and its chemical composition (wt.%) was 0.5–0.9 C, 3.5–5.5 Si,3.0–4.5 B, 15–18 Cr, 14.3 Fe, and Ni balance. [20]
Cast WC particles with an average size of 50 µm were used as the ceramic phase and were composed of WC + W2C eutectic.[20]
The composite powder was composed of 50 wt.% Ni-based alloy and 50 wt.% WC particles and used as the cladding material. [20]

2.5 Geometrical profiles of the composite coatings developed by using LIHC:

Under the same laser processing parameters, the cladding height during LC was much higher than that during LIHC, whereas the cladding width and the HAZ during LC were much smaller than those during LIHC. [20]





The efficiencies of the powder utilization during single-track LC and LIHC decreased with increasing laser scanning speed, but the efficiency of powder utilization during LIHC was higher than that during LC under the same laser scanning speed.[20]

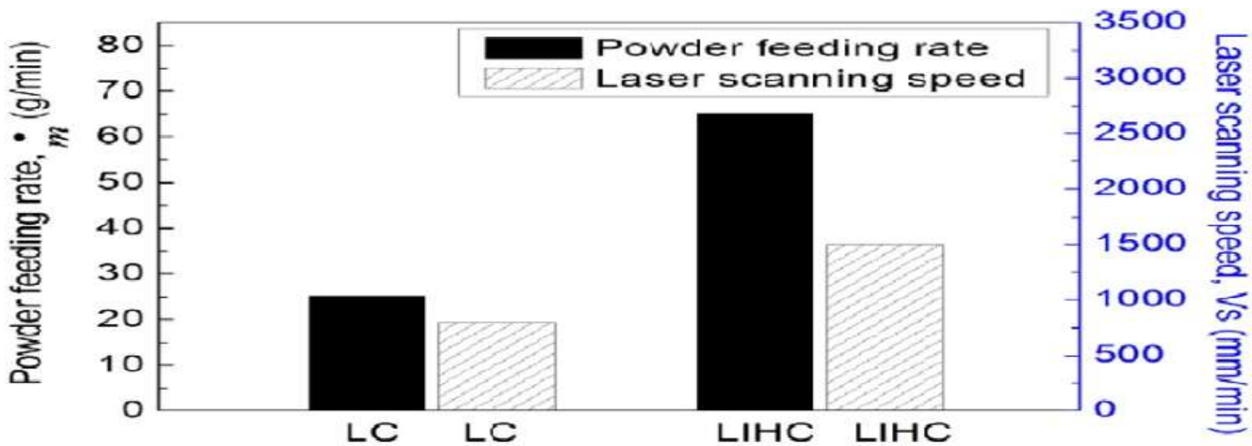


Figure-10: Comparison of processing efficiency between single-track LC and LIHC(20)

Under the same laser processing parameters, the wear rate of the composite coating produced by multi-track LC was much lower than that of the composite coating produced by multi-track LIHC, indicating that the wear resistance of the former was three times higher than that of the latter.[20]

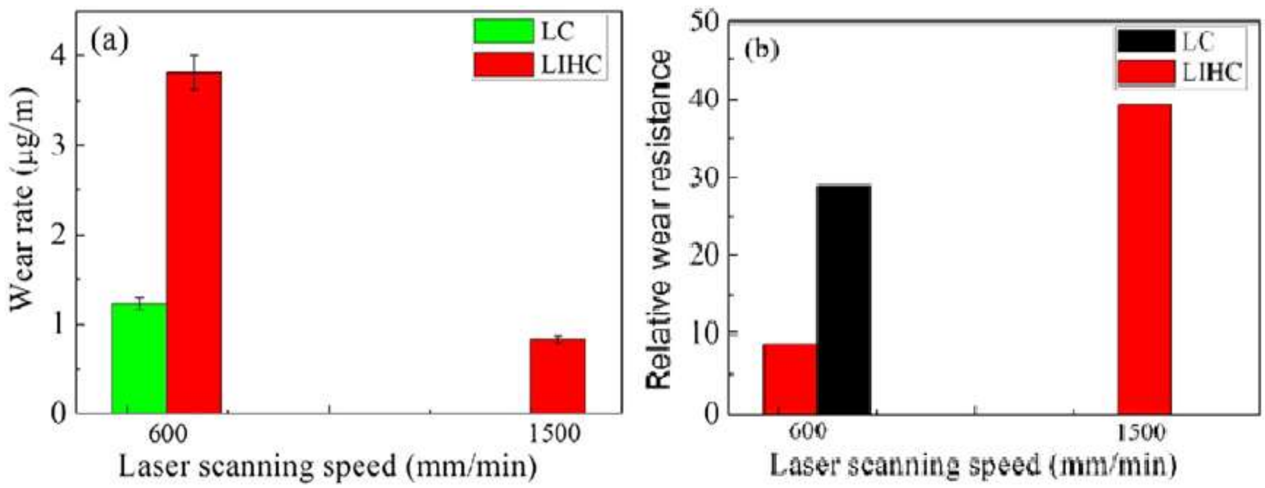


Figure-11: (a) Wear rate and (b) relative wear resistance of the Ni-based 50 wt.% WC composite coatings produced by multi-track LC and LIHC.(20)

3. CONCLUSION

1. The microstructural uniformity is improved with the addition of NiCrBSi.
2. The coating 1 has the highest dilution rate of about 84.9%, and the dilution rate of the coatings (2, 3 and 4) is about 48.6%, 47.6% and 52.6%. The addition of NiCrBSi reduces the dilution rate of the coatings and changes the surface morphology of the coatings from the approximately horizontal shape to the arc-convex shape.
3. The average micro hardness of the coatings (1, 2, 3 and 4) is 745HV 0.1, 976 HV 0.1, 1046 HV 0.1 and 1107 HV0.1. Their fracture toughness is 4.20 MPa m1/2, 3.57 MPa m1/2, 3.02 Pa m1/2 and 2.92 MPa m1/2, respectively. As the increase in content of NiCrBSi, the micro hardness and fracture present the opposite change trend.
4. The wear volume of the coatings (1, 2, 3 and 4) is 2.4113 mm3, 0.7596 mm3, 0.9709 mm3 and 0.2185 mm3, respectively. With the increase in content of NiCrBSi, wear mechanism of the coating 1 is the micro-cutting and that of coating 2 and 3 is changed into the combination of the micro-cutting and the brittle debonding. Finally, wear of the coating 4 is controlled by the brittle debonding. The appropriate addition of Ni (21%) into the 30%WC–NiCrBS cladding material contributes to the improvement in wear resistance of the coating.
5. Under the same laser processing parameters, the cladding height created during single-track LC was much higher than that produced during single-track LIHC, whereas the dilutions, cladding width, HAZ and the efficiency of powder utilization during single-track LC were much smaller than those during single-track LIHC.
6. Under the same laser processing parameters the micro-hardness and wear resistance of the composite coating produced by multi-track LIHC were worse than those of the composite coating produced by multi-track LC.
7. When the laser scanning speed was increased to 1500 mm/min the micro-hardness and wear resistance of the composite coating produced by multi-track LIHC was higher than those of the composite coating produced by multi-track LC.

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