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Mechanical and microstructural characterization of microwave post processed Alloy-718 coating

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Abstract

High Velocity Oxy-fuel (HVOF) sprayed coatings are preferred for depositing almost all materials in numerous industries due to their ease of operation. However, the presence of heterogenous microstructure along with the presence of considerable porosity requires a suitable post processing of as-sprayed coatings. In the present work, the principles of microwave hybrid heating (MHH) were successfully applied for the post processing of HVOF sprayed Alloy-718 coating. The as-sprayed and post-processed coatings were characterised in terms of their microstructure, microhardness, fracture toughness and surface roughness. Pin-on-disc tribometer was used to analyse the abrasive wear behaviour of as-sprayed and post-processed coatings. The post processed coating resulted in significant improvement in mechanical properties of the as-sprayed coatings due to healing of micro-cracks and pores during microwave exposure.

1. Introduction

The surface degradation of materials is mainly caused due to wear and corrosion. The machine tool components like grey cast iron beds and slides are subjected to abrasive wear and should possess an excellent behaviour in terms of tribological and mechanical properties [1–3]. The surface properties of the grey cast iron components can be modified by introducing a layer of suitable material exhibit good wear resistant properties. The coating/cladding methods were cost effective and they are widely used in the industries to modify the surface properties of the components having poor wear and erosion resistance. Thermal spray coatings are now-a-days being used extensively by the manufacturers of machine tools, heavy machineries, power plants and automobile sector [4, 5]. These techniques are very much reliable in terms of producing wear and corrosion resistant coatings. It has been reported that the coatings consisted of the Ni-based superalloys powders are effective for providing the surface failures caused by wear [6]. However, the presence of micro porosities and formation of cracks in the thermal spray coating processes (plasma spraying, high velocity oxy-fuel and flame spraying) have been reported by many researchers [7–9]. Such defects on the surface of the coatings can even deteriorate the sub-surface region. The WC-CO-Cr and Al2O3-40TiO2 coatings were deposited using D-Gun spraying technique were used for the enhancement of abrasion resistance. However, the decomposition of powder due to higher velocity of the process leads to the surging in the porosity level and decrease in bond strength of the deposited coatings [1]. The HVOF falls in the processes with moderate temperature range amongst the thermal spraying techniques [10, 11]. However, the poor adhesion between splats and presence of porosity requires suitable post-processing of HVOF sprayed coatings. The HVOF sprayed NiCrWBSi coatings were heat treated and determined that heat treatments had reduced the porosity considerably, and this reduction was accompanied by pronounced microstructural changes includes more uniform distribution of the hard phases, and a decrease in the number of microcracks and unmelted particles [12]. The HVOF sprayed WC-15NiCr coatings on the mild steel were heated treated in
the nitrogen atmosphere at 750 °C. The effect of heat treatment showed the improved abrasive wear resistance and healed microstructure of the coating [13]. In another study, the potential to improve the tribo-mechanical performance of HVOF sprayed WC-12Co coatings were heat-treated by hot isostatic pressing (HIP) at 920 °C for 2 h at 103 MPa in argon atmosphere in order to investigate the transformation of the amorphous constituents into a crystalline state. The post processed coatings showed the crystallization of amorphous coating phases and increase in elastic modulus and hardness [14].

The post processing can be done by using various techniques such as heat treatment, laser glazing and microwave glazing etc [15–18]. The post processing carried out through laser melting was used to reduce the porosity in the Stellite 6 and Ni-20 Cr coatings [8]. The laser melting process heals the microstructure and increased the microhardness of WC-Co coatings deposited by plasma spraying method [19]. The plasma spraying of bio-medical coatings consisted of HA reinforced with Al2O3 were annealed at 700 °C and showed increase in mechanical properties [20]. Laser glazing is most commonly used post processing technique for the as-sprayed thermal sprayed coatings. However, the laser glazing is not a cost effective process.

Now-a-days microwave processing of materials are gaining popularity due to its specific attributes such as volumetric heating, uniform heating and improved mechanical properties. The improvement in tribological and mechanical properties of flame sprayed Ni-based coatings through microwave route was reported by Zafar et al [9]. Inconel-718 is one of the most commonly used Ni-based material exhibits excellent tribological and mechanical properties. Vasudev et al [2] reported the improvement in surface properties of GCI using HVOF sprayed Alloy-718 coatings. But the presence of micropores, and cracks are inherent with the HVOF sprayed Alloy-718 coatings. In the present work, the post-processing of as-sprayed HVOF Alloy-718 coatings was carried out using microwave route. The effect of microwave exposure was investigated in terms of microstructure and mechanical properties of the microwave processed Alloy-718 coatings. The abrasive wear behaviour of the post processed coatings was also investigated by using pin-on-disc tribometer. The various properties of the post processed Alloy-718 coatings such as microhardness, surface roughness, fracture toughness and abrasive wear resistance were discussed vis-à-vis the as-sprayed coatings.

2. Experimental procedure and materials

2.1. Alloy–718 coating deposition

Initially, the grey cast iron (GCI) was selected as base material and samples of required dimensions of size 20 × 20 × 5 mm³ were prepared by machining on Wire Cut Electric-discharge Machine(WC-EDM). Afterwards the prepared samples were grit blasted prior to the deposition of coating with virgin alumina powder having 18 mesh size. The average roughness (Ra) of 6 ± 0.5 μm has been maintained to ensure a proper mechanical interlocking between the as-sprayed powder and the substrate. The alloy-718 was selected as a coating material which was deposited on the substrate by using HVOF process. A typical SEM micrograph (figure 1(a)) illustrates the spherical morphology of Alloy-718 powder with an average powder particle size of about 45 μm. The EDS of the powder taken corresponding to location 1 indicates the presence of Ni, Fe and Cr as major elements as shown in figure 1(b). The chemical composition (wt%) of the Alloy-178 powder as provided by the supplier is 54.5 Ni, 20.5Cr, 4.9 Nb, 2.9 Mo, 0.7 Al, 1.2 Ti, 0.07 C and Fe balance. The XRD spectrum of Alloy-718 indicates that all elements in powder are present in the form of solid solution of Ni-Cr-Fe. The NiCrAlY was used as a bond coat prior to the deposition of the coating. Here, the main function of bond coat is to provide a rough surface for proper mechanical adherence of the top coat. In addition to this, the bond coat being rich in Ni and Cr may also prevent the diffusion of these elements at high temperature from the coating to the substrate and vice-versa [2].

The chemical composition (wt%) of the bond coat used was 68Ni, 22Cr, 10Al and Y balance. The powder was procured from Alloy Corporation, USA, Ohio with a product code of PAC-9620M. The HVOF spraying of Alloy-718 feedstock powder was performed at research and development by using Hipojet-2700 gun, (Make: M/s Metallizing Equipment Corporation, Pvt. Ltd, Jodhpur, India). The various parameters adopted for the deposition of the Alloy-718 coating is illustrated in table 1. The average thickness of coatings and bond coat was maintained in the range of 220 ± 5 μm and 50 ± 10 μm, respectively.

2.2. Microwave post-processing of Alloy–718 coating

The post processing of as-sprayed Alloy-718 coatings was carried out using an industrial microwave (MH -1514-101-V6, Make: Enerzi Microwave Systems). The schematic diagram of the experimental set-up used for the post-processing of the Alloy–718 coatings through microwave exposure is illustrated in figure 2. Because, the as-sprayed deposits reflect microwave at room temperature due to their low skin depth. Hence, the principles of MHH were applied using a Boron carbide (BC) susceptor (Make: Enerzi Microwave Systems). The BC easily couples with microwave at room temperature and subsequently it transfers heat to Alloy–718 deposits by...
Figure 1. (a), (b) SEM micrograph along with EDS of Alloy-718 powder, and (c) XRD of Alloy-718 powder.

Table 1. High velocity oxy-fuel (HVOF) sprayed process parameters.

| Process parameters for spraying | Alloy-718 coating |
|---------------------------------|-------------------|
| Oxygen flow rate in splh        | 270               |
| Oxygen pressure in bar          | 10                |
| Powder feed rate in g min⁻¹     | 60                |
| Fuel gas (LPG) flow rate in splh| 55                |
| Acetylene Fuel gas (LPG) pressure in bar | 8          |
| Standoff distance (mm)          | 200               |
| Coating Thickness(μm)           | 220–240           |

Figure 2. Schematic diagram of set-up used in post-processing of Alloy-718 coating.
conduction through alumina separator. At high temperature, the Alloy-718 couple with microwave radiation and it results in increase in temperature of the Alloy-718 deposits. The optimum process parameters (exposure time, frequency and power) were selected by using trial and error method for the post processing of Alloy-718 coating based on the available literature of the microwave heating [21–25]. The coated coupons were exposed to microwaves at 2.45 GHz. The power of the microwave radiation was maintained at 1 kW, and exposure time was 900 s. In the present case, it is very difficult to measure the inside temperature of Alloy-718 deposits, because it is covered with BC susceptor. Hence, the temperature of the upper layer of BC was monitored using a non-contact type infrared pyrometer (Make: AMETEK, UK). The optimum temperature of the upper surface of the BC susceptor for the post processing of Alloy-718 deposits were measured to be in the range of 1260 °C to 1270 °C. However, the actual temperature of the Alloy-718 coatings was higher than the measured temperature due to internal heating phenomenon associated with microwave heating. It has been found that at a temperature higher than 1290 °C, the complete melting of coated specimen was occurred due to phenomenon of thermal runaway. On the other hand, at a temperature less than 1250 °C, the complete densification of the as-sprayed coatings was not occurred.

2.3. Characterisations of the coatings

The various phases present in the as-sprayed and microwave processed coatings was detected with the help of x-ray diffraction (XRD) machine. The XRD pattern was obtained using XPert PRO, PANalytical Advanced Diffractometer (Netherlands) with Cu Kα radiation at 40 Ma and a voltage of 45 KV. For microstructural analysis, the as-sprayed and post-processed Alloy-718 coated specimens were prepared according to standard metallographic methods. The coated specimens were cut perpendicular to coatings direction by using metallurgical slow speed diamond cutter. The speed during the cutting was kept at 200 RPM. The cut specimens were polished using emery papers of grades varying from 200 to 1200 and followed by 1/0, 2/0, 3/0 and 4/0 grade polishing papers after—that the cloth polishing with alumina powder was carried out to obtain mirror finish. Further, the polished samples were cleaned using acetone to ensure the removal of any unwanted particles present on the specimens. The microhardness along the cross-section was conducted for bare and coated samples. The 200 g load for a dwell period of 15 s was used to obtain the microhardness. The average of five readings was taken at 5 identical locations along the cross-section with three readings at each location.

Fracture toughness (KIC) is measure of resistance to crack formation in the material. In the present work, the fracture toughness of the as-sprayed and post-processed Alloy-718 coatings was measured with Vickers microhardness tester (Make: Chennai Metco, Model: VHI MD Economat) at a load of 10 kg and dwell period of 15 s. The microhardness values were taken along the cross-section of the coated specimens. The crack lengths parallel to the interface of the coatings were measured from SEM micrographs. The magnitude of the fracture toughness was calculated by using Evans and Wilshaw relationship as given in equation (1) [26].

\[
K_{IC} = 0.079 \left( \frac{f}{a} \right)^{3/2} \log \left( \frac{4.5a}{c} \right)
\]

Where f is the applied load, ‘a’ is the half diagonal length of indent and c is crack length from the centre of the indent.

The arithmetic average surface roughness, root mean square and maximum roughness of the as-sprayed and post-processed Alloy-718 coatings was measured by using contact type surface roughness tester (Model: SJ201, make: Mithutotyo, Japan). The five set of values at different locations was carried out to measure the surface roughness of the coatings. Optical Microscope (Make: Chennai Metco, Tamil Nadu, India) equipped with metallurgical Dewinter 6.0.0 software was used to analyze the porosity of as-sprayed and post-processed Alloy-718 coating. The reported value of porosity is an average of ten readings taken at various locations for a particular specimen. The surface morphology of the as-sprayed and post-processed Alloy-718 coatings was analysed with the help of Carl-Zeiss SEM equipped with energy dispersive spectroscopy (Model: Gemini Ultra Plus). The SEM analysis was carried out to identify the presence of splats, inclusions, semi-melted and melted particles in the as-sprayed and post-processed Alloy-718 coatings. The EDS analysis was carried out for the elemental distribution and composition to confirm the weight percentage (% ) of the various elements present in the coatings.

2.4. Abrasive wear test

The abrasive behaviour of the as-sprayed and post processed Alloy-718 coatings was determined as per ASTM-G99 standard by using pin-on-disc abrasive wear test. The testing samples were in the form of cylindrical pin with 10 mm diameter and rubbed against the SiC emery paper of 400 grit size mounted on the disk of pin-on-disk tribometer to investigate the sliding wear. The loading conditions and other parameters adopted for abrasive wear test are presented in table 2. The specimens were hold by the sample holder and sliding of the specimens was carried out against the SiC abrasive paper of grit size 400 fixed on the rotating disc made of EN31 die-steel.
The weight loss of as-sprayed and Alloy-718 post-processed coatings was measured by using weight balance (Model: ML-220, Make: Mettler Toledo). The worn-out as-sprayed and post-processed Alloy-718 specimens were analysed with SEM micrographs taken at different magnifications for determining the wear mechanism responsible for the failure of the surface.

### 3. Results and discussion

#### 3.1. Microstructural characterization

The as-sprayed coated specimens were subjected to microwave post-processing route as described in section 2.2. The SEM microstructure of the as-sprayed and post processed Alloy-718 coatings is shown in figure 3. It is clear from figure 3(a) that the microstructure of Alloy-718 coatings illustrates heterogeneous microstructure with presence of several micro-pores. The pores were increasing from the substrate towards the surface. Because the already deposited splats are generally compacted with the incoming splats strikes over them. Thus, the maximum porosity and heterogeneous microstructure was observed at the top of the as-sprayed Alloy-718 coatings as shown in figure 3(a). On the other hand, the microwave post processed microstructure indicates the formation of dense and homogenous microstructure along the cross-section of the as-deposited coatings as shown in figures 3(b), (c) respectively. During microwave exposure, the Alloy-718 coatings couples with microwave radiation at high temperature and it causes healing of pores due to melting of splats at high temperature. The splats melted at high temperature and it covers most of the irregularities present in the as-sprayed coatings.

The x-ray maps of post-processed Alloy-718 coating corresponding to SEM micrograph in figure 3(c) are shown in figure 4. These maps showed the denser distribution of major elements (Ni, Cr, Fe) present in the...
coatings as compared to as-sprayed Alloy-718 coating as reported by elsewhere [2]. Further, the aluminium (Al) and chromium (Cr) seems to be little bit higher at the surface of post processed Alloy-718 coatings. This is attributed to the high temperature associated with the post processed coatings. At higher temperature, the various alloying elements present in the Alloy-718 plays a different role. The Al and Cr in the Alloy-718 coatings provides oxidation resistance at high temperature. Thus, the presence of Al and Cr in the top surface of the post processed Alloy-718 coatings indicate the formation oxide layer which mainly consists of Al2O3 and Cr2O3 at high temperature.

The SEM micrographs of the top surface of the as-sprayed and post-processed Alloy-718 coating at different magnifications are shown in figure 5. The SEM micrograph of as-sprayed surface shows the presence of pores and un-melted powder particles at various locations as presented in figures 5(a), (c) and (e) at different magnifications. Whereas, the microstructure of microwave post-processed Alloy-718 coating shows the healing of pores due to flow of material during microwave heating as shown in figure 5(b). The microstructure of the post-processed coating (figure 5(d)) represents the melted splats corresponding to the area under the rectangle as shown in figure 5(b). The melted splats can be observed further at higher magnification in figure 5(f) corresponding to the area under the rectangles shown in figure 5(d). Further, the x-rays maps of the top surface of the microwave assisted post processing coatings are shown in figure 6. Form x-ray maps, it has been found that there is denser concentration of major alloying elements (Al, Ni, Cr) in the coatings, which indicates the reduced porosity in the coatings relative to as-sprayed coatings microstructure. Further, the presence of significant amount of oxygen (O) along with Al, Ti and Cr was also found in the x-ray maps of the top surface of the microwave assisted post-processed coatings; which indicates the formation of oxides of Al, Cr and Ti in the top layer of the coatings.

The XRD spectra of as-sprayed and microwave post processed coatings is shown in figures 7(a) and (b) respectively. From figure 7(b), it is clear that peaks of the major phase present in the post processed coatings is highly suppressed as well as shifted with respect to as-sprayed coatings. The major peaks in the post-processed coatings was observed at 2θ values of 43.81° and 51.02°; whereas, the major peaks in the as-sprayed coatings were observed at 2θ values of 43.45° and 50.49°. The slight shift in peaks indicates that lattice straining in the post processed coatings which leads to densification of the porous as-sprayed deposits. Further, the marginal stressing (compressive) was induced in the microwave processed coatings. This results in improvement in mechanical properties of the post processed Alloy-718 coatings. The results are in agreement with earlier findings also [16]. The XRD spectrum of the post processed coatings also indicates the formation of various oxides (Al2O3, NiO, TiO2 and Cr2O3) along with Ni-Fe-Cr rich solid solution which are further endorsed by topology x-ray maps of the top surface of the coatings (figure 6).
3.2. Microhardness analysis

The microhardness testing of the un-coated, as-sprayed and post-processed Alloy-718 coatings were performed as per the procedure explained in section 2.3. The calculated microhardness values of the substrate, as-sprayed and post processed coatings are plotted in figure 8. The hardness of the post-processed coatings was measured to be about 665 ± 10 HV0.2 which was significantly higher than the hardness (about 560 ± 12 HV0.2) of the as-sprayed coatings. The improvement in microhardness is due to the densification associated with volumetric heating of Alloy-718 coatings during microwave exposure and subsequent homogenisation of the microstructure. The microwave exposures result in densification of coatings through melting of splats. The melted splat fills the micropores and irregularities present in the coating and it results in a homogenous microstructure to be developed inside the coatings. The dense and homogenous microstructure resists the plastic flow of material during indentation and it improved the microhardness of the post-processed Alloy-718 coatings.

3.3. Analysis of fracture toughness

The fracture toughness of the as-sprayed and microwave post-processed Alloy-718 coated specimens were determined as per the procedure described in section 2.3. The SEM micrograph (figure 9) illustrates the
Figure 6. (a) Typical topology SEM image of the microwave post-processed coatings, and (b) x-ray maps corresponds to SEM micrograph of figure 6(a).

Figure 7. XRD pattern of (a) as-sprayed, and (b) post-processed Alloy-718 coating.
indentations made along the cross-section of as-sprayed and post-processed Alloy-718 coatings. It is clear from figure 9 that the cracks were formed in the longitudinal direction of as-sprayed and post-processed coated specimens. Because no cracks appeared in the transverse direction, it indicates the coating has less resistance to crack propagation in the longitudinal direction compared to that of the transverse direction, which is inherent with the directional nature of the properties of the thermal spray coatings. Further, the crack length seems to be significantly larger in the as-sprayed coatings as compared to the post-processed coatings; this indicates that the post-processed coatings offered more resistance to crack propagation than the as-sprayed coatings. The chemical inhomogeneity along with presence of several micropores and cracks enhances the susceptibility of the coatings towards crack initiation and propagation. The various pores and cracks act as a potential site for crack nucleation and propagation because they act as a high concentration stress point. On the other hand, most of the pores were filled in the post processed coatings and it results in the development of homogenous and dense microstructure in the coatings, which enhances the fracture toughness of the microwave processed Alloy-718 coatings. The as-sprayed coated specimen exhibits an average fracture toughness of 3.7 ± 0.30 MPa m\(^{1/2}\), while the microwave post-processed Alloy-178 coatings exhibits 35% higher fracture toughness (4.4 ± 0.20 MPa m\(^{1/2}\)).

3.4. Surface roughness
The average surface roughness (Ra), maximum roughness (Rz) and Root mean square (Rq) roughness of the as-sprayed and microwave post-processed Alloy-718 coatings were evaluated as per the procedure explained in section 2.3. The results obtained after measuring the various types of surface roughness of the as-sprayed and post-processed Alloy-718 coatings are summarised in table 3. The average surface roughness of the post-processed Alloy-718 coatings was observed to 1.9 ± 0.3 μm, which is significantly lower (about 48%) than the
as-sprayed specimens ($Ra = 3.6 \pm 0.4 \, \mu m$). This is attributed to the homogenization and densification of the post-processed Alloy-718 coatings; which is due to healing of the surface pores and cracks due to material flow at high temperature, which improves the surface texture (figure 4). Further, this improved texture lowers the surface roughness of microwave post-processed specimens.

### 3.5. Abrasive wear study

The abrasive wear performance of the as-sprayed coatings and post processed Alloy-718 coatings were determined as per the procedure explained in section 2.4. The cumulative weight loss characteristics and coefficient of abrasive wear of all the tested specimens (substrate, as-sprayed coatings and post processed coatings) are presented in figure 10. The cumulative weight loss data showed the significant weight loss of substrate followed by as-sprayed and then followed by post-processed Alloy-718 coating as shown in figure 10(a). The minimum weight loss was observed in the post-processed Alloy-718 coated specimens among all the tested specimens. This was attributed to the formation of relatively more dense and homogenous microstructure in the post-processed coated specimens as compared to as-sprayed coatings. During post-processing, the Alloy-718 coatings couples with microwave radiation and it results in volumetric heating of Alloy-718 coated specimen at high temperature which results in improved cohesion between splats. It is clear from figure 10(a) that all the samples in the initial stage of contact with the rotating disc showed sudden increase in weight loss. The Archard’s wear relation (equation (2)) was used to calculate the coefficient of abrasive wear for all the tested specimens (substrate, as-sprayed coatings and post processed coatings).

\[
Q = \frac{KW}{H}
\]

Where $Q$ is the wear rate in g m\(^{-1}\), $k$ is dimensionless constant known as abrasive wear coefficient; $H$ is the hardness of the material and $W$ is load in N.

The calculated value of abrasive wear coefficient of all the tested specimens (substrate, as-sprayed and post-processed coatings) are shown in figure 10(b). The post-processed specimens showed the minimum abrasive wear coefficient among all the tested specimens. The improved in fracture toughness and microhardness is the main cause for the higher wear resistance of the post processed Alloy-718 coatings as compared to as-sprayed Alloy 718 coatings.

The SEM micrographs of the worn-out surfaces of substrate, as-sprayed and post-processed specimens were analysed to understand the wear mechanisms. The material from the substrate surface has been plastically deformed and abraded in a dominant way. The deep marks formed on the surface depict the pull–out of the material. The significant abrasion was seen as a wear mechanism on the un-coated worn-out substrate surfaces in the form of deep grooves, ploughing marks and scratching as shown in figures 11(a) and (b), respectively. The
worn-out specimen of as-sprayed Alloy-718 coating showed the abrasion marks on the surface with formation of pits. The scratches formed during the sliding wear are presented in figure 11 (c). Furthermore, the ploughing can be seen on the surface and microcutting action takes place at some locations as observed in figure 11 (d). The microcutting in the coating may occur due to the presence of un-melted particles present on the as-sprayed surface [27]. The interface of the melted and un-melted gets sheared during the ploughing action and microcutting marks are formed on the surface. On the other hand, the worn-out specimen of post-processed coating showed the depressed impression of the counter surface as shown in figures 11(e), (f), respectively. However, there is no deep grooves or material pull-out was observed on the worn-out sample of post-processed coating and this is attributed to the relatively high hardness and fracture toughness of the post-processed coatings which results in enhanced wear resistance of the material [28, 29].

4. Conclusions

In the present work, the various properties of the as-sprayed Alloy-718 coatings were significantly improved through microwave post-processing route. These properties were analysed by using various characterization
techniques to correlate the microstructure of the as-sprayed and post-processed coatings with the mechanical properties. The conclusion drawn from the present work as follows:

1. The microwave post-processing route was successfully applied for the post processing of Alloy-718 coatings for improving its performance and mechanical properties.
2. The XRD spectrum of the post processed Alloy-718 coatings indicates the lattice straining in the Alloy-718 coatings.
3. The post processed coatings exhibit homogenous and dense microstructure due to uniform and volumetric heating phenomenon associated with MHH process.
4. The post processed coatings exhibit high hardness, high fracture toughness and improved abrasive wear resistance than the as-sprayed coatings.
5. The material pulls out causes higher material loss due to inhomogeneous microstructure present in the as-sprayed coatings. The ploughing and shallow marks causes low material removal due to homogenous microstructure present in the post processed coatings.

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References

[1] Vasudev H, Thakur L, Singh H and Bansal A 2018 Mechanical and microstructural behaviour of wear resistant coatings on cast iron lathe machine beds and slides Kovake Materials, Metallic Materials 56 55–63
[2] Vasudev H, Thakur L, Bansal A, Singh H and Zafar S 2019 High temperature oxidation and erosion behaviour of HVOF sprayed Inconel-718 coating Surf. Coat. Technol. 362 366–80
[3] Vasudev H, Thakur L and Singh H 2017 A review on tribo-corrosion of coatings in glass manufacturing industry and performance of coating techniques against high temperature corrosion and wear, i-Manager’s J. Mater. Sci. 3 38–48
[4] Praveen A S, Saraman J, Suresh S and Subramanian J S 2015 Erosion wear behaviour of plasma sprayed NiCrSiB/Al2O3 composite coating Int. J. Refract. Met. Hard Mater 52 209–18
[5] Grewal H S, Singh H and Agarwal A 2013 Understanding liquid impingement erosion behaviour of nickel-alumina based thermal spray coatings Wear 301 424–33
[6] Bala N, Singh H and Prakash S 2017 Performance of cold sprayed Ni based coatings in actual boiler environment Surf. Coat. Technol. 318 50–61
[7] Afzal M, Ajmal M, Khan A N, Hussain A and Akhter R 2014 Surface modification of air plasma spraying WC–12% Co cermet coating by laser melting technique Opt. Laser Technol. 56 202–6
[8] Sidhu B S, Puri D and Prakash S 2005 Mechanical and metallurgical properties of plasma sprayed and laser remelted Ni–20Cr and stellite-6 coatings J. Mater. Process. Technol. 159 347–55
[9] Zafar S and Sharma A K 2017 Microstructure and mechanical properties of microwave post-processed Ni coating J. Mater. Eng. Perform. 26 1382–90
[10] Kaur M, Singh H and Prakash S 2012 High-temperature behavior of a high-velocity oxyfuel sprayed Cr3C2–NiCr coating Metall. Mater. Trans. A 43 2979–93
[11] Sidhu T, Agrawal R D and Prakash S 2005 Hot corrosion of some superalloys and role of high-velocity oxy-fuel spray coatings a review Surf. Coat. Technol. 198 441–6
[12] Gill L, Prato M A and Staia M H 2002 Effect of post-heat treatment on the corrosion resistance of NiWCrBSi HVOF coatings in chloride solution J. Therm. Spray Technol. 11 95–9
[13] Ben Mahmoud T, Khan T I and Farrokhzad M A 2017 Heat treatment effect on wear behaviour of HVOF-sprayed near-nanostructured coatings Surf. Eng. 33 72–82
[14] Al Harbi N and Stokes J I 2015 Optimizing HVOF Spray Process Parameters and Post-heat Treatment for Micro/Nano WC — 12% Co, Mixed with Inconel-625 Powders A Critical Review 32nd International Manufacturing Conference (Queens University, Belfast, 2015, 2nd–4th September) 1–12 (http://programmes.ucl.ac.uk/32nd/delegates/presentation/21/)
[15] Shoja-Razavi R 2016 Laser surface treatment of stellite-6 coating deposited by HVOF on 316L Alloy J. Mater. Eng. Perform. 25 2583–95
[16] Sharma A K, Aravindhan S and Krishnamurthy R 2001 Microwave glazing of alumina–titania ceramic composite coatings Materials Letter 50 295–301
[17] Wang Q, Li L, Yang G, Zhao X and Ding Z 2012 Influence of heat treatment on the microstructure and performance of high-velocity oxy-fuel sprayed WC–12Co coatings Surf. Coat. Technol. 206 4000–10
[18] Murthy J K N, Rao D S and Venkataraman B 2001 Effect of grinding on the erosion behaviour of a WC–Co–Cr coating deposited by HVOF and detonation gun spray processes Wear 249 592–600
[19] Mateos J, Cueto S M, Ferna ndez E and Vijdane R 2000 Tribological behaviour of plasma-sprayed WC coatings with and without laser remelting Wear 239 743–91
[20] Singh A, Singh G and Chawla V 2018 Influence of post coating heat treatment on microstructural, mechanical and electrochemical corrosion behaviour of vacuum plasma sprayed reinforced hydroxyapatite coatings J. Mech. Behav. Biomater. Mater. 85 20–36
[21] Bansal A, Vasudev H, Sharma A K and Kumar P 2019 Investigation on the effect of post weld heat treatment on microwave joining of the Alloy-718 weldment Material Research Express 8 p1–15
[22] Bansal A et al 2015 Structure–property correlations in microwave joining of Alloy-718 JOM 67 2087–98
[23] Bansal A et al 2014 Characterization of bulk stainless steel joints developed through microwave hybrid heating Mater. Charact. 91 34–41
[24] Sharma A K and Gupta D 2012 On microstructure and flexural strength of metal–ceramic composite cladding developed through microwave heating Appl. Surf. Sci. 258 5583–92
[25] Gupta D and Sharma A K 2014 Microwave cladding: a new approach in surface engineering J. Manuf. Process. 16 176–82
[26] Evans A G and Wilshaw T R 1976 Quasi-static solid particle damage in brittle solids-I, observations analysis and implications Acta Metall. 24 939–56
[27] Sharma A K and Krishnamurthy R 2010 Sliding wear characterization of microwave-glazed plasma-sprayed ceramic composites Proc. Inst. Mech. Eng. 224 497–511
[28] Zafar S and Sharma A K 2014 Development and characterisations of WC–12Co microwave clad Mater. Charact. 96 241–8
[29] Zafar S and Sharma A K 2016 Investigations on flexural performance and residual stresses in nanometric WC-12Co microwave clads Surf. Coat. Technol. 291 413–22