J Therm Spray Tech (2019) 28:378–390
https://doi.org/10.1007/s11666-019-00825-9

PEER REVIEWED

Bristle Blasting Surface Preparation in Thermal Spraying

Yingying Ding[1] · Hui Li[1] · Yingliang Tian[1]

Submitted: 30 May 2018 / in revised form: 3 December 2018 / Published online: 23 January 2019

Abstract The adhesive strength to the substrate plays an important role in the performance of thermal-sprayed coatings and could determine the coating's service life. It depends to a large extent on the state of the substrate surface prior to coating deposition. In this work, a novel surface pretreatment technique was introduced to thermal spraying, namely, bristle blasting. The adhesive strengths of a plasma-sprayed metallic coating (Ni_5Al) and a ceramic coating (Al_2O_3) were examined and compared to that of coatings sprayed with conventional grit blasting surface pretreatment. A mild steel and an aluminum alloy were selected as substrate materials. The results indicated that bristle blasting could be a practical solution for steel and aluminum alloys when grit blasting is not applicable on site. The adhesion of the sprayed coatings with different pretreatments increased sequentially from mechanical grinding, bristle blasting to grit blasting. The adhesive strength of the Ni_5Al coating deposited on the bristle-blasted substrate reached 60% of the adhesive strength of a coating deposited with the traditional grit-blasting pretreatment, while for the alumina coating, it was only about 30%. Moreover, the effect of substrate materials should be considered when using bristle blasting as a surface preparation.

Keywords adhesive strength · APS · bristle blasting · sand blasting · surface morphology · surface preparation

✉ Hui Li
lee.hui@gmail.com

Yingying Ding
dingyingying@emails.bjut.edu.cn

[1] College of Materials Science and Engineering, Beijing University of Technology, Beijing, China

Introduction

Thermal-sprayed coatings have been widely used in various industrial sectors for surface engineering solutions. The coating needs to have sufficient adhesive strength with the substrate, which is also the minimum service requirement. Usually, the substrate surface is carefully prepared prior to spraying (e.g., grit blasting) in order to offer a cleaned and roughened surface providing an adequate bonding for the deposited coating (Ref 1). This procedure is a necessary step, which plays a crucial role in the overall performance of the coating. In the past several decades, some novel methods of substrate surface pre-treatment have been explored, including high-pressure water jet blasting (Ref 2, 3), dry ice blasting (Ref 4, 5), pulsed laser ablation (Ref 6), laser surface texturing (Ref 7) and mechanical patterning (Ref 8). Those promising methods are meaningful when the operation of grit blasting is unavailable or undesirable. For example, soft substrate materials such as aluminum alloys, copper, etc., suffer greatly from embedded grit particles at the substrate/coating interface. In addition, in some on-site operations, it is quite difficult to use standard grit-blasting machines that usually require air compressors and consume large amounts of grit. Also, environmental concerns have been raised over the noise and hazardous dust by-product. A surface pretreatment using mobile facilities with simple operation is more advantageous for these industrial applications.

In recent years, bristle blasting has emerged as a new approach in surface preparation that has drawn attention from industry (Ref 9). This process is fundamentally a mechanical abrasion process using a rotating brush-like wheel. The wheel consists of many sharpened, high-strength steel wires whose tips are specially designed with a forward-angle bend, i.e., the shank of the wire is bent in the direction of rotation (Fig. 1). During operation, the rotating bristle tips strike the target surface with a kinetic energy similar to the impact of blasting grit. This process repeated continuously results in thousands of localized impacts, rebounds, and the formation of craters, thereby leaving a cleaned and roughened surface (Ref 9). The main advantage of this technology is its simplicity and ease of use. The bristle blaster is half a meter long and several tens of centimeters high; it can be easily driven by an electric or pneumatic motor. It can be mounted on an automated positioner or handled manually so that the operation only needs a very small space, unlike grit blasting typically requiring a large soundproof booth or protection. Some workers have tried to use bristle blasting as a surface pretreatment for painting and have shown that it was possible to generate a roughened surface, whose average roughness (R_a) was about 3.35 µm (Ref 1). The data reported in (Ref 10) indicated that a comparable adhesive strength of painting coating was obtained with bristle-blasting surface preparation compared to traditional grit blasting. Nevertheless, this technique has not been tested in the field of thermal spraying. The purpose of this work is, thus, to examine the feasibility of applying bristle blasting in thermal spraying. A metallic coating (Ni_5Al) and a ceramic coating (Al_2O_3) were selected as coating materials. The tested substrates included a mild steel substrate (A283) and an aluminum alloy (7075). Taking into account that the primary contribution to a sprayed coating's adhesion is the mechanical interlocking caused by surface roughness, the coatings were deposited on substrates treated by three different surface preparation methods: standard grit blasting, bristle blasting, and mechanical grinding, results in a flat surface.

Experimental

Preparation of Substrate

Two kinds of materials were used as a substrate, mild steel (A283) and an aluminum alloy (7075). Each substrate was a cylindrical-shaped sample measuring 25 mm of diameter with a thickness of 10 mm. The feedstock included a fused and crushed Al_2O_3 (15-45 µm) powder and a mechanically cladded Ni_5Al (38-74 µm) powder. The alumina possesses high chemical stability (Ref 11) and the thermally sprayed alumina coating's adhesion is mainly dependent on the mechanical anchoring effect (Ref 12, 13). The sprayed Ni_5Al coating has been commonly used as a bond layer. Owing to the exothermic reactions of Ni and Al occurring in the spraying process, this type of coating has good adhesive strength and is less sensitive to the surface roughness (Ref 14-16).

Three different procedures of surface preparation were concerned, namely, the traditional grit blasting, bristle blasting, and mechanical grinding. The main purpose of this work was to compare the grit blasting and bristle blasting as a surface pretreatment. The mechanical grinding was used as a control group, specially used for examining the effect of surface roughness. In the case of the grit-blasting process, the blasting abrasive used was 20-mesh corundum particles (Pigeon Group), the blasting air pressure was 0.6 MPa and the blasting distance was 60 mm, with the blasting nozzle perpendicular to the sample during the blasting. The mechanical grinding was performed manually on an automatic grinding machine using 800# SiC sandpaper.

The bristle blasting was conducted using a commercial blaster (Monti SE-677-BMC), whose wheel rotation speed was fixed at 2150 rpm. With respect to the penetration

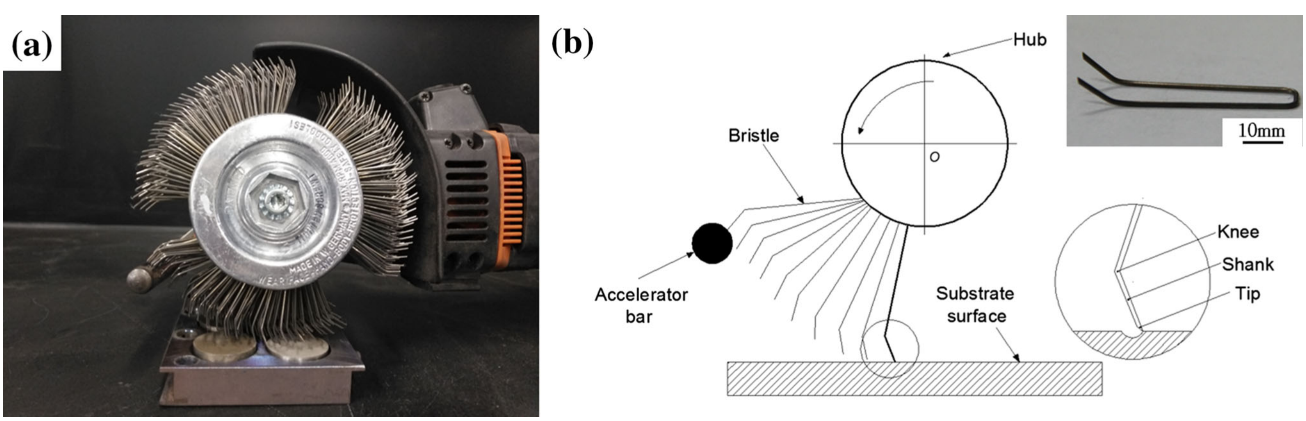

Fig. 1 A standard bristle blaster (a) and its schematic illustration (b)

depth between the bristle tips and the substrate surface, as per the work of Stango (Ref 9), a penetration depth of 1.5 mm can induce a significant change of the surface profile. When the depth was increased to 4 mm, there was no marked increase of surface roughness for a larger penetration depth. Moreover, the greater penetration depth adversely led to a shortened life of bristle. The penetration depth was therefore set at depths of 1, 2 and 3 mm in the present work. In order to minimize the process deviation caused by manual operation, the blaster was mounted on a mechanical arm to control the penetration depth with a stable sweeping speed. It should also be mentioned that the 'penetration depth' here was just the nominal depth between the bristle tips and the substrate surface when the mounted hub was in a static condition. During the processing, the rotating hub made of fabrics and polymer must endure a certain deformation due to the resistance coming from the tips. As a consequence, the instantaneous penetration depth varied, which to a large extent depended upon several factors including the hardness of the substrate, the stiffness of the rotor, the sharpness of the bristles, etc.

The experiment groups are listed in Table 1; in each group, there were six coating samples prepared, among which four samples were subjected to the standard tensile test, the remaining two samples were used to characterize the surface topography and the coating microstructure, respectively.

Substrate Surface Morphology Observation

In order to characterize the surface topographic morphology, a confocal laser scanning microscope (LEXT OLS4100) was used to observe the surface. There are several well-established techniques for surface topography characterizations, such as contacting stylus-type profilometer and non-contact systems including confocal microscope, atomic force microscope, and white light interference scanner. Among them, the principle of laser confocal microscope scanning (Ref 17) is based on an optical imaging technique with enhanced optical resolution and contrast, giving a good balance of high test accuracy and adequate testing speed. The equipment is also capable of characterizing the surface 3D morphology and the 2D profile in different sections. The surface texture parameters can also be estimated automatically. The principle of 3D surface morphology characterization is based on layer slicing and imaging reconstruction. The 2D image was firstly acquired by *X*–*Y* scanning on the substrate surface by a 405-nm wavelength laser beam. By adjusting the focal point along the *Z*-axis, a series of successive 2D images were collected at evenly spaced heights. The precision of the step height of the focus is about 10 nm which also determines the vertical resolution of the characterization. Finally, the 3D surface morphology was reconstructed by numerical processing on the basis of the collected data of the 2D images (Ref 18, 19).

Coating Preparation

The coating was sprayed by a Metco 9Mb plasma gun mounted on a robot (Motoman HP20) and the spraying parameters are given in Table 2. The spraying parameters also have an important influence on the coating adhesive strength, but this issue was not the focus here. As a rule of thumb, the spraying parameters were taken from the spraying table recommended by Metco (Ref 20). Coatings with a minimum thickness of 380 μm were prepared. Such a coating thickness is a mandatory requirement in the

Table 1 List of the experiment groups

Trial no.	Coating materials	Substrate materials	Treatment method
M-S-G	Ni_5Al	A283	Grinding
M-S-GB			Grit blasting
M-S-BB			Bristle blasting
M-A-G		7075	Grinding
M-A-GB			Grit blasting
M-A-BB			Bristle blasting
C-S-G	Al_2O_3	A283	Grinding
C-S-GB			Grit blasting
C-S-BB			Bristle blasting
C-A-G		7075	Grinding
C-A-GB			Grit blasting
C-A-BB			Bristle blasting

Table 2 Plasma spraying parameters

Coating materials	Voltage, V	Current, A	Ar, L/min	H_2, L/min	Distance, mm	Powder feed rate, g/min
Ni_5Al	64	500	45	9.5	140	50
Al_2O_3	65	500	45	9.5	90	30

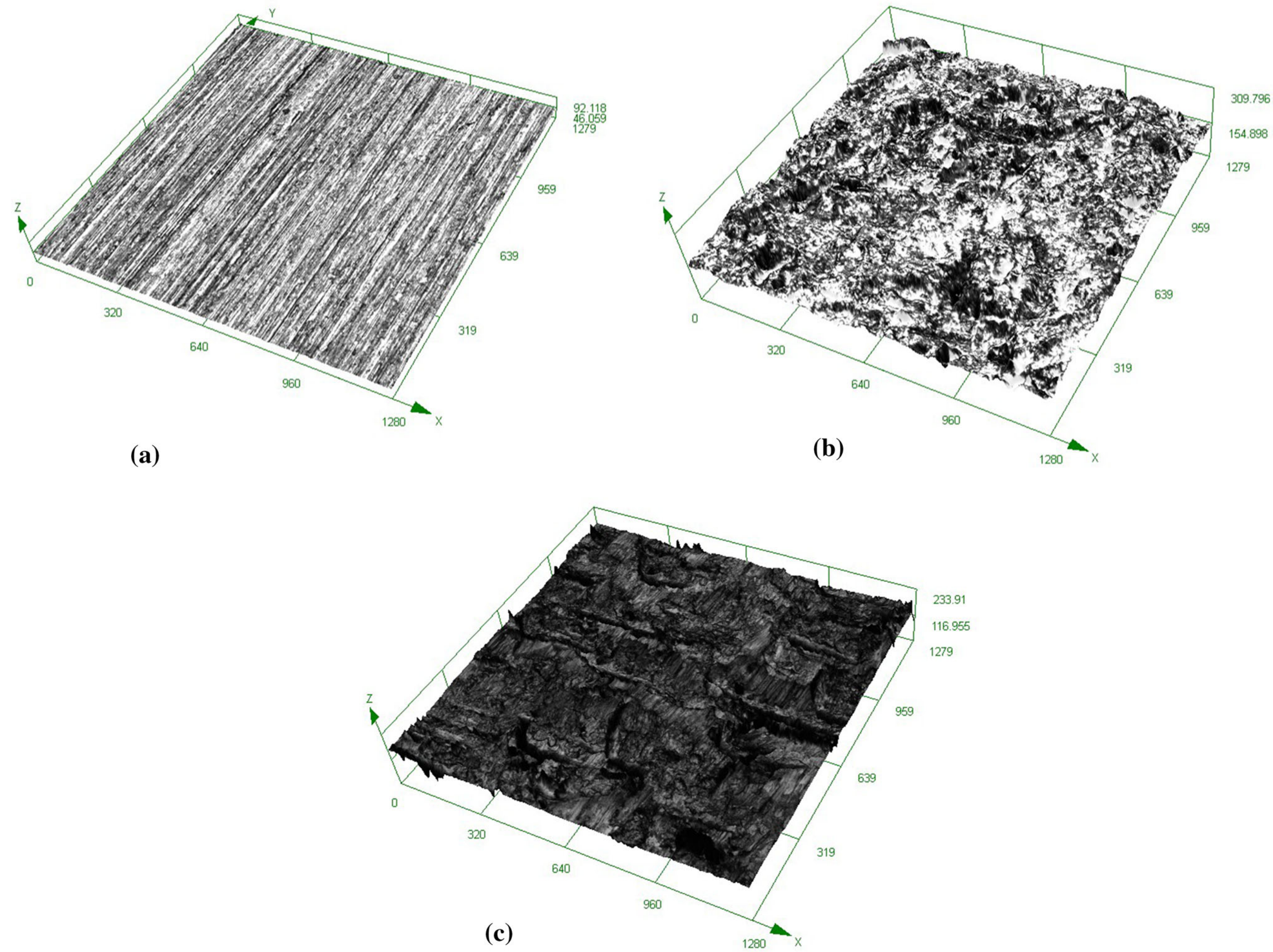

Fig. 2 The surface morphology of the steel substrate treated by different methods: (a) grinding, (b) grit blasting, (c) bristle blasting (3 mm)

ASTM standard (ASTM C633-08) for adhesive strength measurement of thermal spray coatings, which is believed to be sufficient to prevent the penetration of epoxy into the coating–substrate interface which results in measurement errors.

Test of the Adhesive Strength

The adhesive strength of the coating was measured according to the ASTM C633-08 standard. A film-type epoxy resin (FM 1000; Cytec) was applied to glue the coating to the stainless steel rod. The resin was cured at 185 °C × 2.5 h and then the glued sample was transferred tfortensile testing during which the load was applied at a constant speed of 1 mm/min until rupture occurred.

Results

Substrate Surface Morphology

In general, it is believed that mechanical bonding makes the primary contribution to the adhesion of thermal spray coatings. This effect is highly correlated to the surface roughness. Some previous studies have summarized several characteristic parameters of the surface morphology.

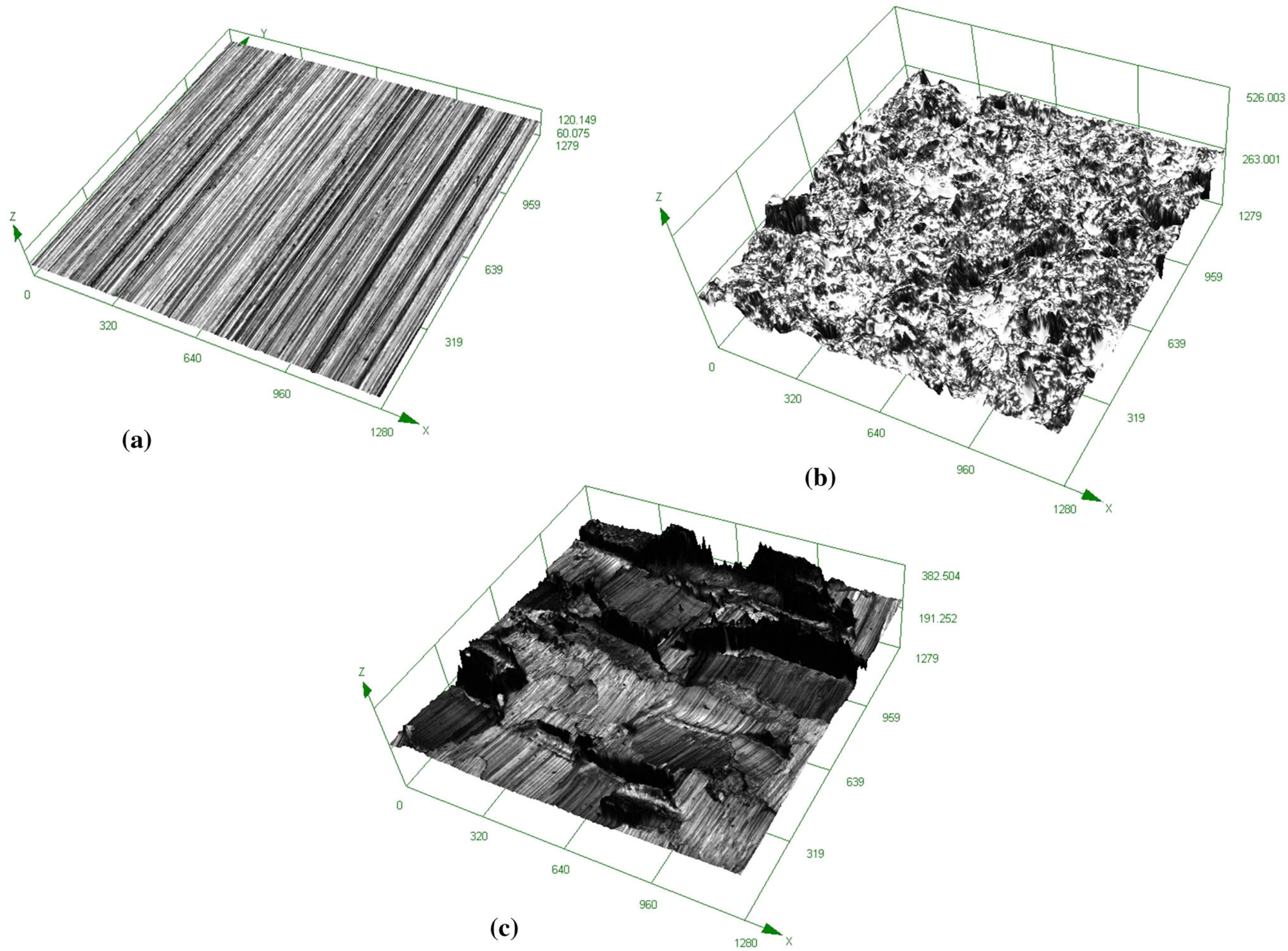

Fig. 3 The surface morphology of the aluminum alloy substrate treated by different methods: (a) grinding, (b) grit blasting, (c) bristle blasting (2 mm)

One is the usually used parameter of averaged roughness (R_a), which is the arithmetic average of the absolute height of peaks and valleys from the mean line of the surface profile. Another one is the parameter of $R_{\Delta q}$, which describes the averaged slope of the roughness profile. This parameter was proposed by Nylén (Ref 21), and it was believed to be more appropriate to interpret the anchoring effect induced by surface roughness. The last one is the parameter of R_{sk}, which is a measure of the skewness of the surface profile. R_{sk} is negative when more deep valleys are present on the surface profile and vice versa. When it equals zero, the surface profile is almost symmetrical. This parameter is considered as a suitable indication of the effect of surface morphology on the liquid droplet wetting, and it can finally affect the adhesive strength of the sprayed coating (Ref 22).

The surface morphologies of the treated steel substrate and aluminum alloy substrate were observed by a laser confocal microscope, as shown in Fig. 2 and 3, respectively. And the measured surface roughness data are summarized in Fig. 4.

During the testing, it was found that the parameter R_{sk} is quite sensitive to the scale of measurement on the roughened surface. In particular, when the length of the tested square surface was decreased to several micrometers, the fluctuation of R_{sk} was extremely large, i.e., the measurement on a randomly selected zone of several micrometers square had already lost its representation. Considering that the size of a flattened splat is always in the range of 100-200 μm (Ref 23), the characterization of R_{sk} was performed on a 200 μm square, at which point the deviation of measurement became normal.

The morphology of the as-ground substrate surface is shown in Fig. 2(a) and 3(a), respectively. The whole surface was flat and there were a large number of straight lines along the grinding direction. The averaged roughness (R_a) was the smallest (0.78 ± 0.0166 μm for 7075 and 1.158 ± 0.131 μm for the aluminium) as well as the slope

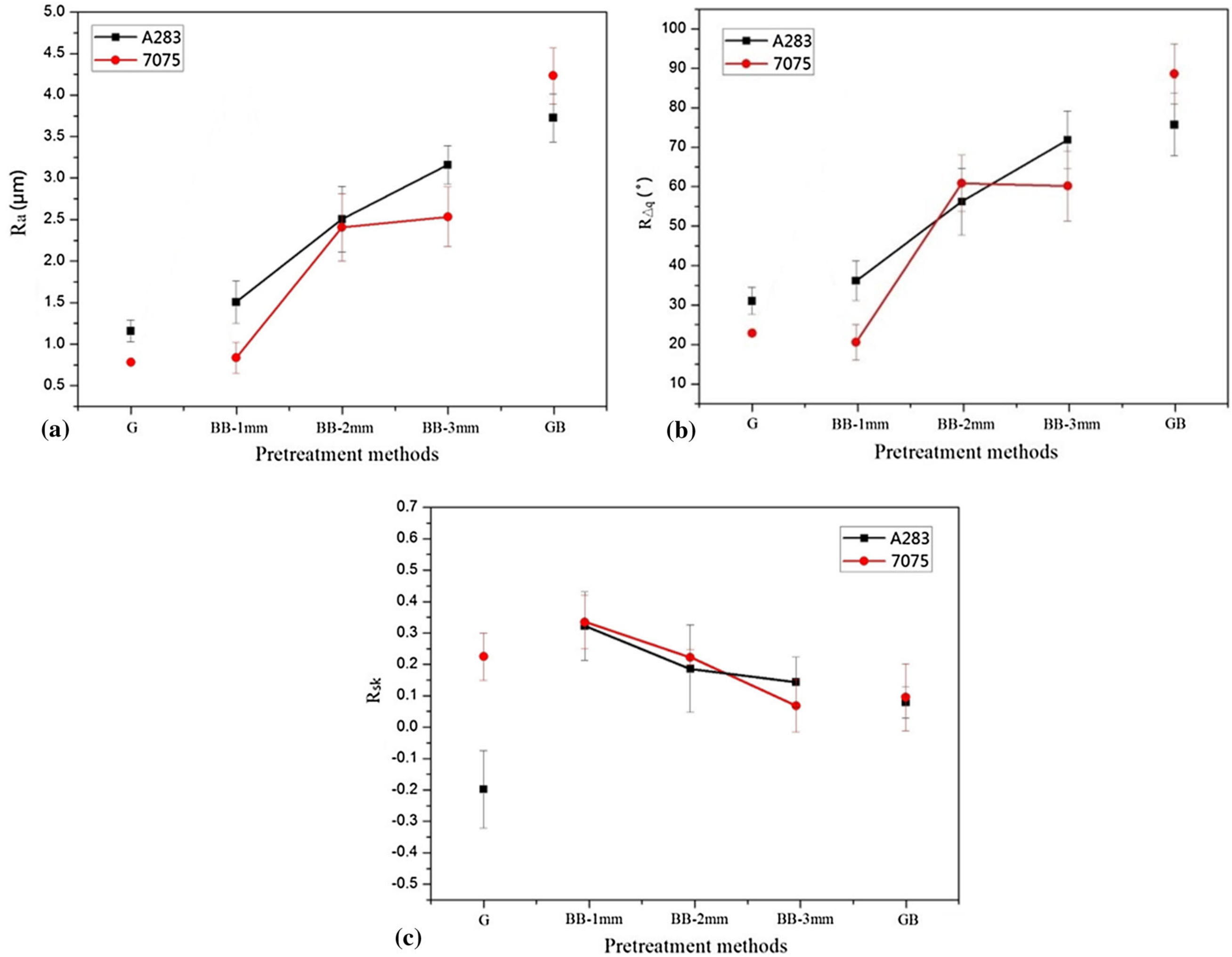

Fig. 4 Surface roughness of substrate with different treatment. (a) R_a, (b) $R_{\Delta q}$, (c) R_{sk}; *G* grinding, *GB* grit blasting, *BB* bristle blasting

of the roughness profile ($R_{\Delta q} \sim 22.839 \pm 0.685°$ for the aluminum 7075 and $31.045 \pm 3.41°$ for the stainless steel A283). These scratch lines were slight and had a negligible impact on the surface roughness. Comparatively speaking, the grit-blasting treatment offered the roughest surface, with an average roughness R_a of about 4 µm (4.388 ± 0.436 µm for 7075 and 3.757 ± 0.292 µm for A283) while $R_{\Delta q}$ was 85°($89.013 \pm 7.630°$ for 7075 and $74.843 \pm 7.923°$ for A283). With respect to the bristle-blasted surface, although a bright metal shining color can be seen by visual inspection, the surface morphology was not as rough as that of the grit-blasted substrate. Moreover, the surface roughness varied when the penetration of the bristle tips was changed. In the case of the 7075, the surface average roughness R_a increased abruptly from 0.834 ± 0.185 to 2.450 ± 0.606 µm when the penetration depth changed from 1 to 2 mm, implying that more substrate materials were chipped out. However, there was no distinct difference between the samples treated with a penetration depth of 2 and 3 mm in terms of average roughness (R_a) and profile slope ($R_{\Delta q}$). This is presumably due to the plastic deformation of the 7075 substrate when the bristles continuously impacted on the substrate, as observed in Fig. 4. As the penetration depth increased, there was a tendency for a gradually decrease of the surface skewness (R_{sk}), indicating that the profile asperities were shallow and depressed. For the A283, when the penetration depth increased, the roughness increased linearly, as shown in Fig. 4. When the penetration depth was 3 mm, the average surface roughness (R_a) was approximately that of the grit-blasted surface, as well as the profile slope ($R_{\Delta q}$). At this point, the penetration depth was not possible to be increased for the A283 because of the insufficient kinetic energy of the rotating wire. This result indicated that the influence of substrate materials should also be considered when bristle blasting is used to roughen the substrate.

In order to make the bristle blasting and grit blasting comparable in terms of surface roughness, the penetration

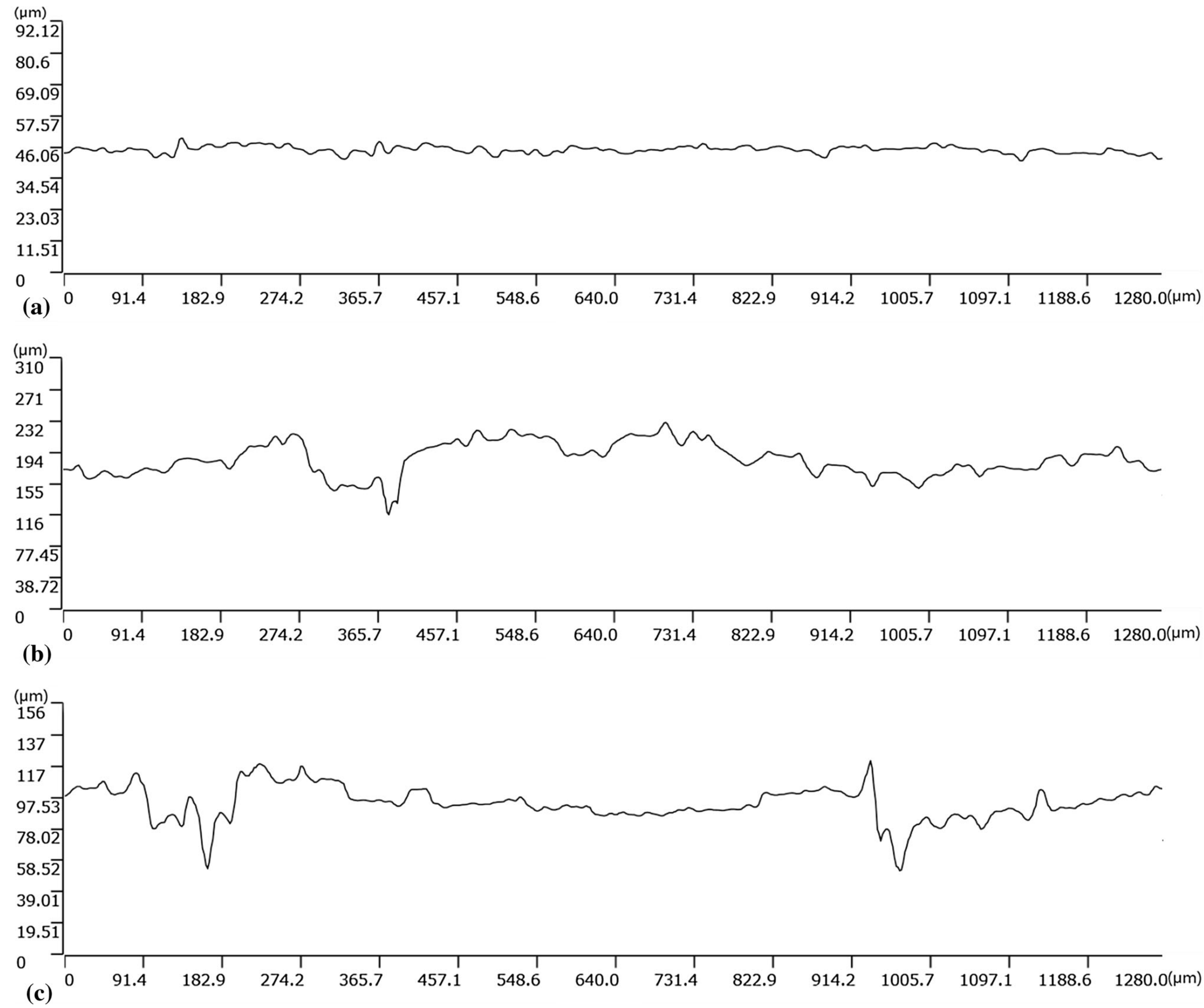

Fig. 5 2D profile of the steel substrate surface (A283) with different treatments: (a) as-ground, (b) as grit blasted, (c) as bristle blasted with 3 mm penetration

of 3 mm was selected as the treatment parameter for A283 while for 7075 the penetration depth was set to 2 mm. It was worth noting that, although the value of average surface roughness was close, the surface texture of the bristle-blasted surface was not as uniform as the one treated by grit blasting. This is also quite understandable, because during the bristle blasting the surface roughening was produced by the intensive striking of bristle wires. Those wires were braided together on the wheel hub and there was a visible gap of several millimeters between two adjacent bristles. As a consequence, the undulation of surface morphology of the substrate treated by bristle blasting was not as dense as that one treated by grit blasting, as shown in Fig. 5. The space between the peaks and valleys of the surface profile was much enlarged compared to that of the grit-blasted surface (350 versus 50 µm, Fig. 5).

Adhesive Strength of the Coating

Since the adhesion of the thermal-sprayed Al_2O_3 coating mainly depends on the mechanical seizure effect (Ref 24), all the coatings deposited on the flat ground substrate was directly peeled off without any loads, i.e., zero adhesive strength of coating to substrate. This phenomenon is predictable, and the poor adhesion is partly ascribed to the accumulated residual stress resulting from the mismatched shrinkage between the coating and the substrate (Ref 25).

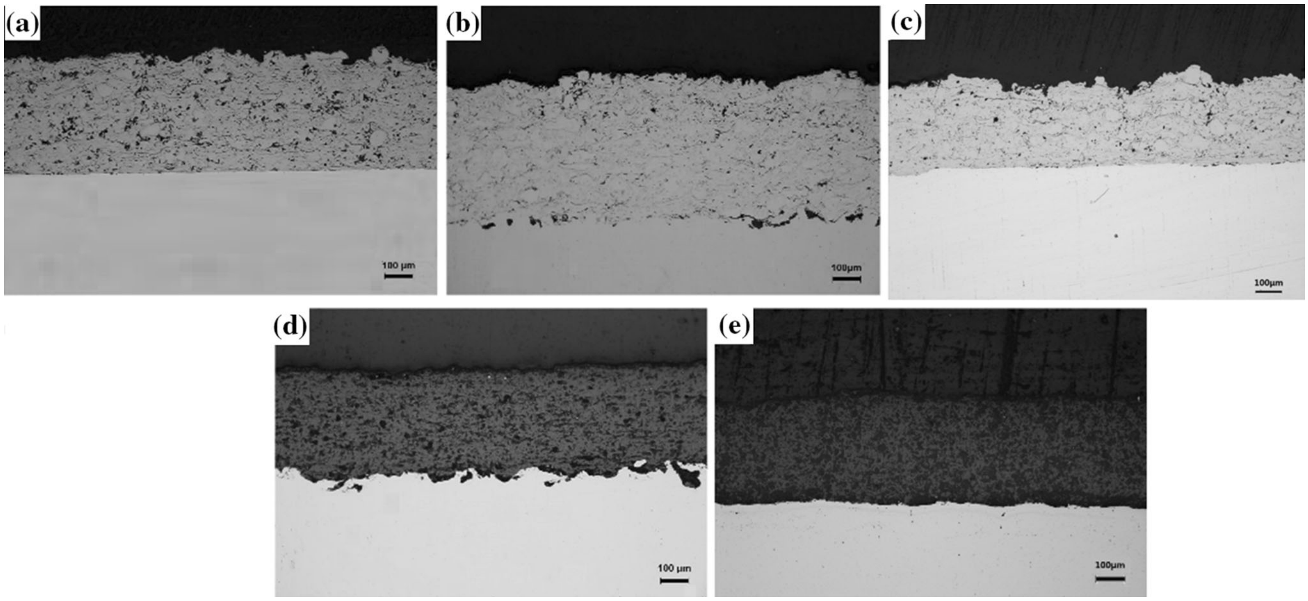

Fig. 6 The cross-section observations on different coatings: (a) M-A-G, (b) M-A-GB, (c) M-A-BB, (d) C-A-GB, (e) C-A-BB

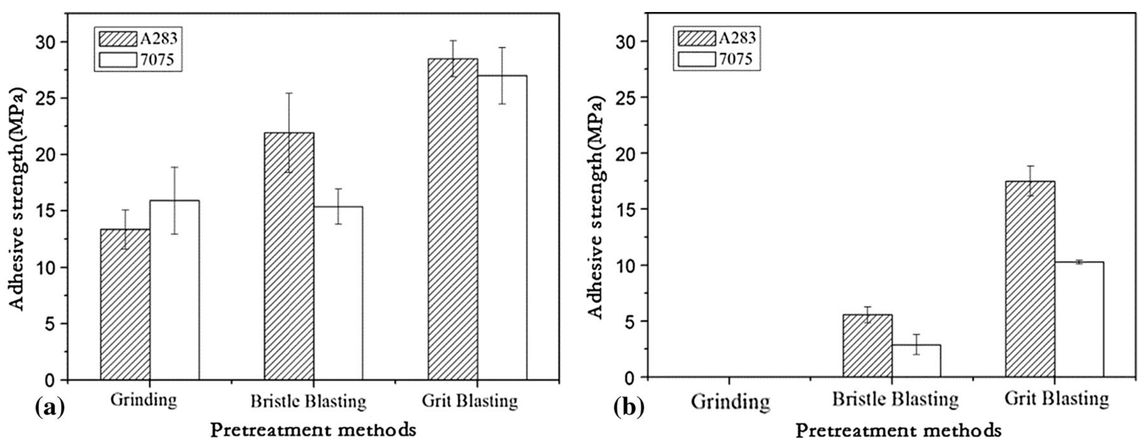

Fig. 7 The adhesive strengths of the Ni_5Al coating (a) and the Al_2O_3 coating (b) on substrates with different surface pretreatments

The cross-section observation of different coatings is given in Fig. 6, from which it can be seen that the boundary between the coating and the substrate was clear-cut for those ground samples having a flat interface (Fig. 6a). In contrast, the grit-blasted surface was much rougher, but obviously there were many residue grits embedded in the interface, particularly for the soft aluminum alloy substrate (Fig. 6b and d). The bristle-blasting treatment offered a compromised result. The interface between the bristle-blasted substrate and the coating was fairly clean without any grit residues, but the roughness was moderate, i.e., lower than the grit-blasted sample but higher than the ground sample (Fig. 6c and e).

The measured adhesive strengths of the Ni_5Al coating and the Al_2O_3 coating are shown in Fig. 7. It should be mentioned here that all the samples were fractured at the coating/substrate interface during the tensile testing, i.e., adhesive-type failure not cohesive-type failure. It can be concluded from the results that the adhesive strength of the coating on the grit-blasted substrate was the highest, i.e., 28 ± 1.6 MPa for the Ni_5Al coating and 25 ± 2.5 MPa for the Al_2O_3 coating. This result is very close to other reports, e.g., 30 MPa for a Ni_5Al coating (Ref 26) and 23 MPa for a Al_2O_3 coating (Ref 27). The mechanical grinding surface pretreatment yielded the worst adhesive strength. This is quite reasonable because generally the main contribution of coating adhesion stems from the mechanical interlocking between the roughened substrate and the accumulated splat. It is interestingly found that the bristle blasting yielded an acceptable strength. The Ni_5Al coating reached 60% of the level of the one with grit-blasting treatment,

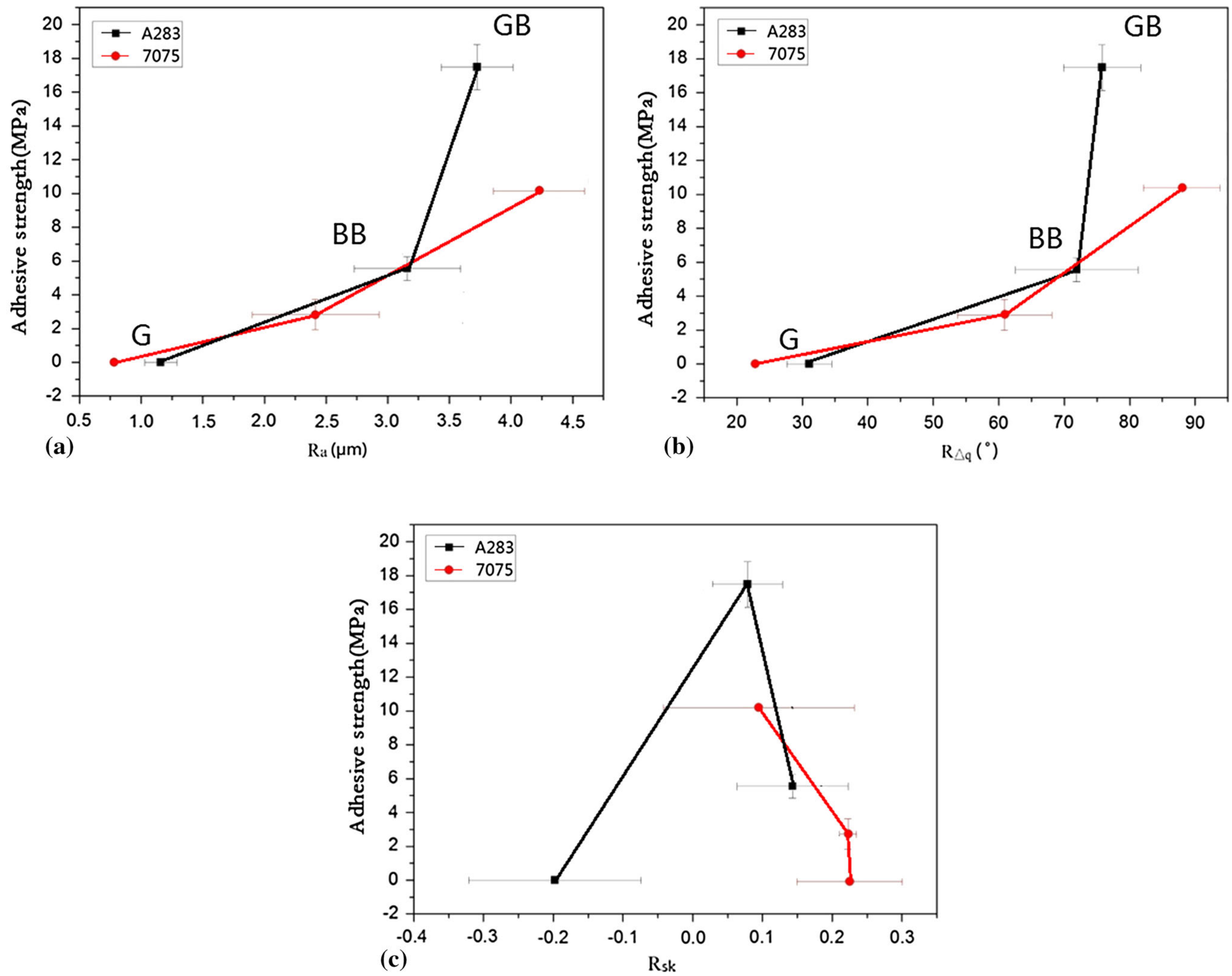

Fig. 8 Dependence of Al_2O_3 coating adhesion upon different surface roughness parameters: (a) R_a, (b) $R_{\Delta q}$, (c) R_{sk}

while in Al_2O_3case of the Al_2O_3 coating, it was lower (30%).

Discussion

Effect of Surface Pretreatment on Surface Topography

As grit blasting is a well-established surface pretreatment in the thermal spraying industry, many research works focusing on this technique were performed in the early years (Ref 28-30). It was demonstrated that a number of processing parameters have a great influence on the surface morphology and, finally, on the coating's adhesive strength, including the blasting angle, blasting pressure and blasting distance. An obvious drawback of grit-blasting surface preparation is the grit residues at the interface, particularly for soft materials. Although the interfacial residual grit can be removed by a subsequent ultrasonic cleaning step (Ref 31), it is difficult to be applied on site. This effect can be fully exempted when using bristle blasting as surface preparation. The most attractive feature of bristle blasting is the process simplicity and cost-effectiveness, particularly for on-site operations. It is not easy to collect and to recycle the massive rebounded abrasive particles when grit blasting is applied in an open space. The process of bristle blasting is flexible and the processing efficiency is also satisfied, being comparable to a standard grit blasting and mechanical roughening. According to the experience in the laboratory, the processing speed can be about 1 sq m of surface in 1-2 min, which is much higher than laser texture processing.

During the bristle blasting, the surface abrasion relies on enormous excavation of the metal surface by the bristle tips, and finally many localized shoveled craters

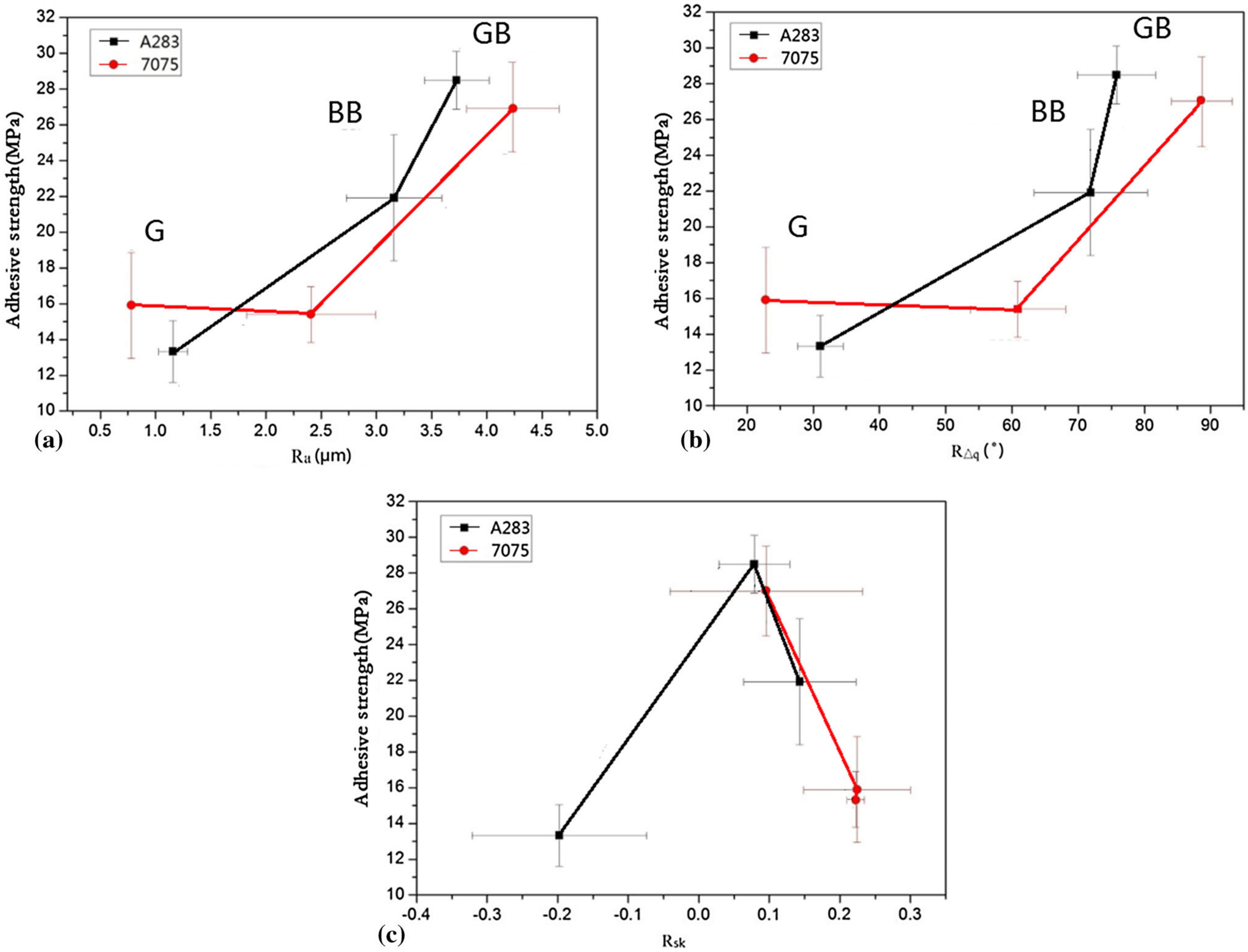

Fig. 9 Dependence of the Ni_5Al coating adhesion upon different surface roughness parameters: R_a, (b) $R_{\Delta q}$, (c) R_{sk}

accumulates on the surface (Ref 9, 32). The continuous impact of the bristle tips differs greatly from the conventional surface peening process. The 7075 aluminum alloy substrate which is a work-hardening-sensitive material was tested for surface hardness. The results showed that the hardness of the sub-surface layer on a blasted sample was 158.89 HV, while that of the non-treated sample was 158.55 HV, implying that almost no hardening effect was introduced by the bristle blasting.

The current work was only a preliminary study on the feasibility of using bristle blasting as alternative to grit blasting as a surface pretreatment. The bristle blaster used was a commercial device, whose rotation speed was fixed at a speed of 2150 rpm. The impact of each bristle tip has a similar effect with respect to the impact of a single blasting grit. During the process, the rotation speed, the length of the bristles as well as theri mass are the main factors determining the striking energy of the bristles.

The morphological difference of the surface between grit blasting and bristle blasting can be explained by the different material removal behavior. The grit-blasted surface consisted of abundant randomly distributed peaks and valleys (Ref 33), which is a result of the cumulative effect of large amounts of the blasting particles. Compared to the grit-blasted surface, the pits and protrusions resulting from the impact of the bristles were not randomly distributed on the bristle-blasted surface (Ref 34). In a localized area as small as a few hundred microns, the surface showed a texture which corresponded to the craters excavated by a single bristle tip (Fig. 1).

Correlation Between Coating Adhesive Strength and Surface Morphology

The dependence of the coating adhesion with respect to surface roughness is shown in Fig. 8 and 9. It can be seen that the adhesive strength of the coating had a good correlation to R_a and $R_{\Delta q}$, particularly for the examined Ni_5Al coating. This is consistent with the results of Nylén (Ref 29). The correlation of coating adhesive strength on the

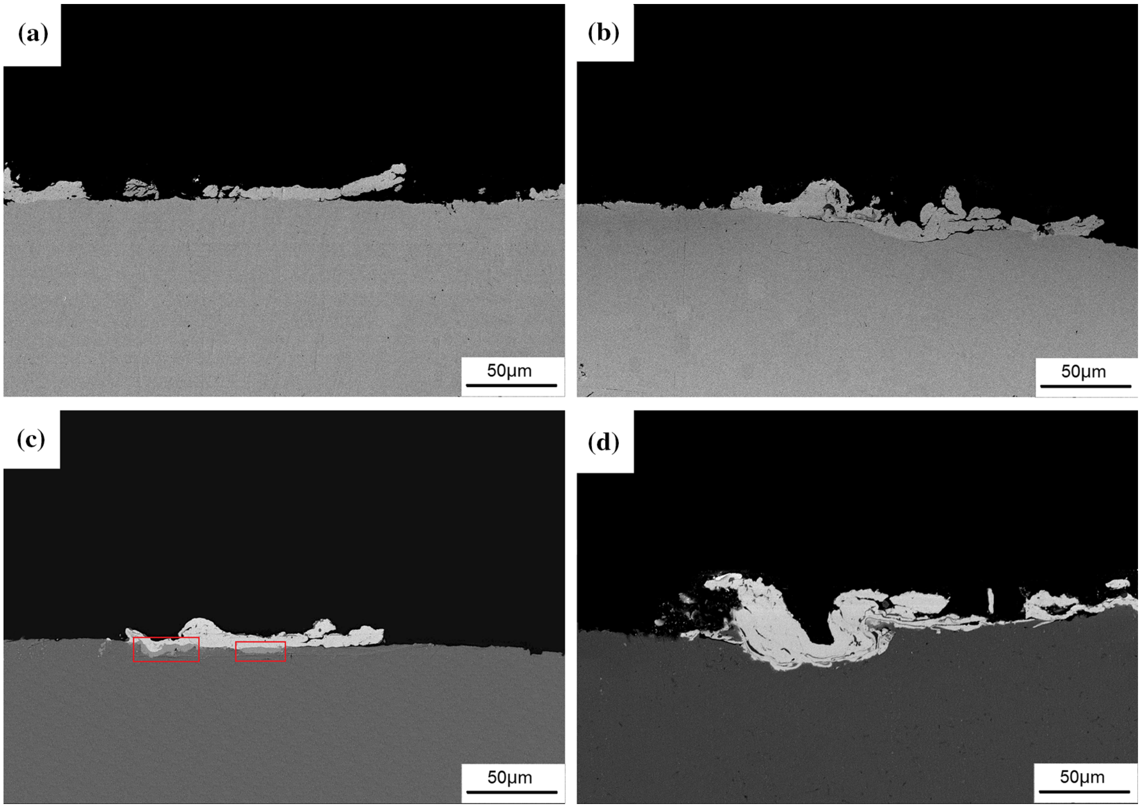

Fig. 10 SEM observations on coating residues: (a) M-S-G, (b) M-S-BB, (c) M-A-G, (d) M-A-BB

substrate surface skewness (R_{sk}) was not clear. It seems that the surface with a symmetric profile with a slightly positive skew (R_{sk} ~ 0.1) was more favorable. Neither a negative skewness nor a more positive skewness is beneficial for the improvement of interfacial bonding. Cedelle (Ref 22) measured the static wettability of a flat surface to the melting droplets. Their results indicated that a very flat surface (R_a ~ nm) with a symmetric profile, i.e., R_{sk} close to zero, leads to the worst wetting condition. The influence of surface static wetting on the adhesive strength of the coating is still ambiguous. It is difficult to correlate the coating adhesive strength and surface skewness from the perspective of droplet wetting.

It has been acknowledged that the morphology of a substrate surface has to be adapted to the granulometry of the sprayed powder (Ref 28, 35, 36), more specifically, the size of the sprayed splats. This was illustrated by the early works performed by Mellali (Ref 28, 36), in which the mechanical interlock effect of a plasma-sprayed Al_2O_3 coating was more readily achieved provided that most of the molten liquid droplets penetrate into the undercuts. If the splat diameter was much smaller than the distance between the peaks and the valleys, the adhesion is poor. They gave a rough estimation that the splat diameter should be 2-3 times of that distance of the surface irregularities, whereupon the coating adhesion increased with the increase of the surface roughness (R_a).

The difference of adhesive strength between the Ni_5Al coating and the Al_2O_3 coating is also acceptable. More Ni_5Al coating residues can be found on the ruptured sample surface. From the cross-sectional characterization on the residues of the Ni_5Al coating (Fig. 10), there was an indication of local substrate melting on the outmost layer of the substrate underneath the sprayed splat, particularly on the Al_2O_3 which has a lower melting point. This coating is a typical metallic material with an exothermic characteristics likely promoting the formation of local metallurgical bonding. That can also explain why the sprayed Ni_5Al coating on a flat substrate also had good adhesive strength. In contrast, the Al_2O_3 coating can only rely on the mechanical interlocking effect governed by the surface roughness. As a consequence, the adhesion of the sprayed Al_2O_3 coating declined rapidly when the surface roughness decreased. The effect of metallurgical bonding originating from the localized cold-welding of the sprayed particles onto the substrate can be little influenced by the surface roughness, but this is, however, not the common case for a thermally sprayed coating.

Conclusions

This work explored the feasibility of applying bristle blasting as a surface preparation in the field of thermal spraying. Although the roughening mechanism of bristle blasting is not well-established and, some in-depth study is needed, this novel technology is examined for thermal sprayed coatings for the first time. The main preliminary results are:

1. The adhesive strength of thermally sprayed coatings deposited on substrates with different pretreatment methods was sequentially increased from grinding, bristle blasting to girt blasting. For the Ni_5Al coating, the bristle-blasting surface pretreatment yielded about 60% of the adhesive strength of the grit blasting method, while for the Al_2O_3 coating, that ratio was only 30%.
2. Compared to the Ni_5Al coating, the Al_2O_3 coating was sensitive to the variation of surface roughness, particularly for the non-roughened substrate such as the substrate treated by bristle blasting or mechanical grinding.
3. The bristle-blasting treatment could be a solution for steel and aluminum alloy substrates when grit blasting is not applicable. However, the substrate material should be considered for the selection of blasting parameters.

Acknowledgment The financial support from the Natural Science Foundation of China (No. 51271007) is gratefully acknowledged.

References

1. A. Guzanová, J. Brezinová, D. Draganovská et al., A Study of the Effect of Surface Pre-treatment on the Adhesion of Coatings, *J. Adhes. Sci. Technol.*, 2014, **28**(17), p 1754-1771
2. T. Samson, D. Macdonald, R. Fernández et al., Effect of Pulsed Waterjet Surface Preparation on the Adhesion Strength of Cold Gas Dynamic Sprayed Aluminum Coatings, *J. Therm. Spray Technol.*, 2015, **24**(6), p 1-10
3. K. Knapp and A. Taylor, Waterjet Roughened Surface Analysis and Bond Strength, *Surf. Coat. Technol.*, 1996, **86-87**(96), p 22-27
4. S. Dong, B. Song, B. Hansz, H. Liao et al., Study on the Mechanism of Adhesion Improvement Using Dry-Ice Blasting for Plasma-Sprayed Al_2O_3 Coatings, *J. Therm. Spray Technol.*, 2012, **22**(2-3), p 213-220
5. S. Dong, B. Song, B. Hansz et al., Study on the Mechanism of Adhesion Improvement Using Dry-Ice Blasting for Plasma-Sprayed Al_2O_3 Coatings, *J. Therm. Spray Technol.*, 2013, **22**(2-3), p 213-220
6. H. Li, S. Costil, H. Liao et al., Surface Preparation by Using Laser Cleaning in Thermal Spray, *J. Laser Appl.*, 2008, **20**(1), p 12-21
7. R. Kromer, C. Verdy, S. Costil et al., Laser Surface Texturing to Enhance Adhesion Bond Strength of Spray Coatings—Cold Spraying, Wire-Arc Spraying, Atmospheric Plasma Spraying, *Surf. Coat. Technol.*, 2018, **352**(25), p 642-653
8. K. Bobzin, F. Ernst, K. Richardt et al., Thermal Spraying of Cylinder Bores with the Plasma Transferred Wire Arc Process, *Surf. Coat. Technol.*, 2008, **202**(18), p 4438-4443
9. R.J. Stango and P. Khullar. Recently developed bristle blasting process for corrosion removal, in *DoD Corrosion Conference, Washington, DC* (2009)
10. N. Wilds. Bristle blasting as a method for surface preparation, in *NACE Corrosion Conference*, *UK* (2009).
11. V. Selvarajan, P. Saravanan, and M.P. Srivastava, Experimental Study of Particle Deposition Characteristics of Alumina Using Plasma Spraying, *J. Therm. Spray Technol.*, 2001, **10**(1), p 138-141
12. G.D. Girolamo, A. Brentari, C. Blasi et al., Microstructure and Mechanical Properties of Plasma Sprayed Alumina-Based Coatings, *Ceram. Int.*, 2014, **40**(8), p 12861-12867
13. N. Shikina, O. Podyacheva, V. Kosarev et al., Formation and Study of Porous Alumina and Catalytic Coatings by the Use of Cold Gas Dynamic Spraying Method, *Adv. Manuf. Process.*, 2015, **31**(11), p 1521-1526
14. M.A. Khan, S. Sundarrajan, M. Duraiselvam et al., Sliding Wear Behavior of Plasma Sprayed Coatings on Nickel Based Superalloy, *Surf. Eng.*, 2015, **33**(1), p 35-41
15. S.C. Deevi, V.K. Sikka, C.J. Swindeman et al., Reactive Spraying of Nickel–Aluminide Coatings, *J. Therm. Spray Technol.*, 1997, **6**(3), p 335-344
16. S.M. Hashemi, M.H. Enayati, and M.H. Fathi, Plasma Spray Coatings of Ni-Al-SiC Composite, *J. Therm. Spray Technol.*, 2009, **18**(2), p 284-291
17. H. Rashid, Comparing Glazed and Polished Ceramic Surfaces Using Confocal Laser Scanning Microscopy, *J. Adv. Microsc. Res.*, 2012, **7**(3), p 208-213
18. S.M. Shah, J.P. Crawshaw, and E.S. Boek, Three-Dimensional Imaging of Porous Media Using Confocal Laser Scanning Microscopy, *J. Microscopy*, 2016, **265**(2), p 261
19. C.A. Banzhaf, L.L. Lin, N. Dang et al., The Fractional Laser-Induced Coagulation Zone Characterized Over Time by Laser Scanning Confocal Microscopy—A Proof of Concept Study, *Lasers Surg. Med.*, 2018, **50**(1), p 70
20. P. Fauchais, Topical Review: Understanding Plasma Spraying, *J. Appl. Phys.*, 2004, **37**(37), p 86
21. F. Bahbou and P. Nylén. Relationship Between Surface Topgraphy Parameters and Adhesion Strength for Plasma Spraying, Thermal Spray connects: Explore its surfacing potential. ITSC 2005, E. Lugscheider, Ed., (Basel, Switzerland), The Material Information Society, 2005, p 1027–1031
22. J. Cedelle, M. Vardelle, and P. Fauchais, Influence of Stainless Steel Substrate Preheating on Surface Topography and on Millimeter- and Micrometer-Sized Splat Formation, *Surf. Coat. Technol.*, 2006, **201**(3), p 1373-1382
23. P.L. Fauchais, J.V.R. Heberlein, and M.I. Boulos, *Thermal Spray Fundamentals*, Springer, US, 2014, p 784-785
24. S. Adachi and K. Nakata, Effect of Plasma Spraying Parameters on Anisotropic Feature of the Mechanical Property of Plasma Sprayed Al_2O_3 Coating, *Mater. Sci. Forum*, 2008, **580-582**(3), p 471-474
25. J.A. Haynes, B.A. Pint, W.D. Porter et al., Comparison of Thermal Expansion and Oxidation Behavior of Various High-Temperature Coating Materials and Superalloys, *High Temp. Technol.*, 2004, **21**(2), p 87-94
26. L. Pawlowski, *The Science and Engineering of Thermal Spray Coatings*, 2nd edn. (John Wiley & Sons, England, 2008), p 26–34
27. S.C. Hua, H.G. Wang, L.Y. Wang et al., Microstructure and Properties of Multi-function Micro-plasma Sprayed Al_2O_3 Coatings, *Int. Conf. Surf. Eng.*, 2007, **373-374**(8), p 51-54

28. M. Mellali, A. Grimaud, A.C. Leger, and P. Fauchais, Alumina Grit Blasting Parameters for Surface Preparation in the Plasma Spraying Operation, *J. Therm. Spray Technol.*, 1997, **6**(2), p 217-222
29. M.F. Bahbou, P. Nylén, and J. Wigren, Effect of Grit Blasting and Spraying Angle on the Adhesion Strength of a Plasma-Sprayed Coating, *J. Therm. Spray Technol.*, 2004, **13**(4), p 508-514
30. D.J. Varacalle, D.P. Guillen, D.M. Deason et al., Effect of Grit-Blasting on Substrate Roughness and Coating Adhesion, *J. Therm. Spray Technol.*, 2006, **15**(3), p 348-355
31. S.J. Yankee, R.L. Salsbury, and B.J. Pletka, Quality Control of Hydroxylapatite Coating: Properties, Processes and Applications, *Thermal Spray*, T. Bernecki, Ed., ASM International, Materials Park, 1991, p 505-513
32. R.Z. Wang, Over View on the Shot Peening Principle and Its Strengthening Mechanisms for Metallic Materials, *Surf. Eng.*, 2012, **25**(6), p 1-9
33. K. Bobzin, M. Öte, T.F. Linke et al., Influence of Process Parameter on Grit Blasting as a Pretreatment Process for Thermal Spraying, *J. Therm. Spray Technol.*, 2015, **25**(1), p 1-9
34. R.J. Stango, R.A. Fournelle, and J.A. Martinez. Bristle Blast Surface Treatment of Welded Joints Fabricated from Commercial Ship Construction Steel, *Corrosion*, 2011, Paper No. 11417
35. R. Kromer, J. Cormier, and S. Costil, Role of Powder Granulometry and Substrate Topography in Adhesion Strength of Thermal Spray Coatings, *J. Therm. Spray Technol.*, 2016, **25**(5), p 933-945
36. M. Mellali, P. Fauchais, and A. Grimaud, Influence of Substrate Roughness and Temperature on the Adhesion/Cohesion Of Alumina Coatings, *Surf. Coat. Technol.*, 1996, **81**(2-3), p 275-286