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Evaluation The Optimization of Thermal Barrier Coating Stripping Methods on Inconel 939 Gas Turbine Vanes

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Abstract

Thermal Barrier Coatings (TBCs) are widely used in power plants and aircraft engines. TBCs are exposed to high temperatures and repeated changes in operating parameters, which determine their service life, or Equivalent Operating Hours (EOH). This study evaluates three stripping methods — HCl 6 & 12 mol, HCOOH 6 & 12 mol, and grit blasting — for removing a Yttria-Partially Stabilised Zirconia (YPSZ) top coat and MCrAlY bond coat from Inconel 939 vanes. Stripping rate, surface roughness, microstructure, and coating completeness were compared. Grit blasting had the highest stripping rate (605 µm/hour) but left residual bond coat and an interdiffusion zone (IDZ) with poor homogeneity. HCOOH methods were ineffective, leaving thick residues and high surface roughness (7.2–7.8 Ra). HCl 12 mol removed all layers but caused carbide coarsening. HCl 6 mol achieved complete layer removal, a stripping rate of 22.8 µm/hour, acceptable roughness (3.33 Ra), and no significant microstructural damage. In conclusion, chemical stripping using HCl 6 mol is the most optimal method for TBC removal from Inconel 939 vanes.

INTRODUCTION

The world's energy needs are increasing every year. According to the Statistical Review of World Energy 2022, the world's total energy consumption increased by 5.8% over the period 2011 to 2021, from 520.90 EJ to 595.15 EJ (BP plc, 2020). Technological development is necessary to meet the growing demand for affordable energy, which is directly related to the efficiency of power generation equipment. Increasing the firing temperature can improve the efficiency of turbine components (Schilke, 2004). Thermal coating technology is increasingly becoming a fundamental method for enhancing the properties of materials against elevated firing temperatures. In particular, it is an effective and versatile method used to obtain coatings of various thicknesses with a favourable cost-to-quality ratio in the field of gas turbines in the power generation sector. The surface strength of the base material can be improved through the use of antioxidant compounds in top coats, such as Yttria-Partially Stabilised Zirconia (YPSZ), while the low thermal conductivity of the zirconia layer helps lower the operating temperature of the components (Rickerby & Matthews, 1991).

The zirconia system, which functions as a heat barrier or top coat, is applied over the MCrAlY layer, which acts as an adhesive layer between the zirconia layer and the substrate and is commonly referred to as the bond coat (Scrivani, 2000; Scrivani et al., 2003).

In power plants, the repair and inspection of equipment are necessary to ensure its reliability (Alvarez-Alvarado et al., 2022; Blaabjerg et al., 2023; Karimova & Piriyev, 2024; Nazarychev et al., 2025; Safiyev et al., 2024; Suci et al., 2025). Protective layers such as the top coat and bond coat must be removed from the base material — a process known as stripping — prior to inspection. This inspection is carried out during the overhaul period for turbine blades and vanes that have not yet exceeded the creep time limit of the base material. Components whose inspection results meet the accepted criteria are reconditioned for reuse; those that have suffered significant damage are deemed unserviceable. A component therefore undergoes stripping, inspection, repair, recoating, and treatment before it can be returned to service (Yang et al., 2020).

A critical requirement of the stripping procedure is to ensure complete removal of the coating layer without damaging the base metal (Molęda et al., 2023; Safiyev et al., 2024; Suci et al., 2025). The stripping process must not cause corrosion or surface hardening of a component, and must ensure minimal dimensional changes to its geometric characteristics. The removal of MCrAlY layers remains a complex challenge in industrial production, for which a perfect solution has not yet been found (Scrivani et al., 2000; Bardi et al., 2004).

There are several methods used to carry out the stripping process, including grit blasting, autoclaving, and chemical cleaning. Grit blasting is a mechanical method in which a stream of abrasive media — such as aluminium oxide, silicon carbide, or sand — is directed at the surface of a component under high air pressure to remove contaminants. During this process, the particles striking the surface exert a strong influence on the subsurface microstructure, affecting both the matrix and its precipitates. In practice, care must be taken to minimise damage to the bond coat and substrate alloys. If not performed properly, grit blasting can damage the surface of the base material, cause uneven erosion, introduce geometric distortion to the protective layer, and result in surface contamination with aluminium oxide. This contamination negatively affects the tensile bond integrity of the protective layer.

In the chemical cleaning method, the bond coat layer is stripped using acid-based chemicals that trigger the release of the coating, with the addition of a corrosion inhibitor to prevent unintended chemical reactions on other areas. Since the chemical reaction on the coating surface cannot be controlled manually, it may result in surface corrosion (Scrivani et al., 2005). Therefore, the soaking duration must be carefully regulated to avoid damage to the base metal surface.

This research focuses on a comparison of bond coat (MCrAlY) removal methods carried out using hydrochloric acid (HCl) and methanoic acid (HCOOH) based chemical solutions, compared to grit blasting using aluminium oxide grit 160. These three methods serve as the reference approaches for the stripping process in this study. The results of the different stripping method treatments will be analysed in relation to processing efficiency and macro- and microstructural analysis of the base material composition. It is hoped that the findings of this study will identify methods that preserve the fundamental structure of the base material while optimising processing time efficiency in carrying out the stripping process.

METHOD

The vane to be tested is first removed from the top coat layer using grit blasting grit 160. The vane is then cut to form a specimen measuring 5 x 10 cm. 5 specimens were carried out the process of stripping the bond coating layer and intermediate zone with 3 different methods The first stripping method is by using chemical hydrochloric acid (HCl) as many as 6 moles and 12 moles and the addition of inhibitor corrosion fluid, the temperature of the liquid is maintained at a temperature of 50 -60oC. The second stripping method is by using 6 moles and 12 moles of chemical methanoic acid (HCOOH), the temperature of the liquid is maintained at 50 – 60oC, and the addition of corrosion *inhibitor fluid*. The specimen that will be carried out *the chemical cleaning* process is previously coated with *silica* in the base metal area which does not have a coating layer. *Silica* serves to protect the base metal from corrosion due to chemical immersion. The third method is to carry out the stripping process with grit blasting using 160 mesh.

During the chemical cleaning process, the specimen is weighted every 2 hours to determine the weight of the graded layer

Material Testing After Stripping Process

Micrography Testing

Samples of test specimens that have been *stripped* and are confirmed to have no *coating* layer will be cut into coupons. The coupons that have been mounted are then polished using the tegraforce-1 struers machine.

After passing the polishing process, the test specimen will be etched using 10 grams of $CuSO_4$, 50 ml of HCl, and 50 ml of H_2O. The etching process is carried out to make several layers corroded so that metallographic tests can be carried out.

The metallographic test was carried out using the Olympus DSX-CB instrument with a magnification of 50 microns, in order to determine the grain limit and gamma precipitation on the test object.

This test aims to test whether there is a change in gamma precipitation on the surface of the test specimen against each method. Changes in gamma precipitation that are increasing or coursing will reduce the stability of the microstructure and resistance to thermal deformation. The gamma precipitation value that is considered optimal in INCONEL 939 material is 0.05 – 0.08 μm (Xu et al., n.d.). The less change in gamma precipitation on the surface of the base material, the better the method is considered.

Roughness Testing

The effect of the stripping process as a whole as well as the possibility of corrosion or degradation damage to the substrate surface was investigated through visual inspection, metallographic analysis, and determination of three-dimensional (3D) surface roughness parameters (Scrivani et al., 2005). To test the roughness on the surface of the test piece, the

Mitutoyo surftest SJ-310 measuring instrument is used so that the comparison of surface roughness in each method can be known.

Roughness on the surface of the base metal is related to the quality during the *recoating* process , the higher the *roughness* value, the more difficult *the recoating* process will be.*Roughness* is also related to the presence of crack initiators, so the recommended *roughness* value will affect the lifetime of the *vane*. The recommended roughness value (Ra) is 3.0 – 5.0 µm. The surface roughness value will be compared to each cycle or *stripping* time on each method.

SEM-EDS

Specimens that have been stripped are cleaned using an ultrasonic cleaner. Specimens that have been cleaned are carried out by Scanning Electron Microscope (SEM) equipped with an X-ray energy spectrometer (Energy Dispersive Spectrometer/EDS) used to observe the morphology of the fault surface, microstructure, and chemical composition (Gani et al., 2016). After the roughness test is continued, the test specimen needs to be tested using SEM to determine the contaminant content on the surface of the test object.

The value of the contaminant tested is related to the *recoating process*, if there are many contaminants and corrosion then the adhesion of the *coating layer* cannot adhere optimally. The value of contaminants on the base metal surface should be below 0.5% of the test surface area as much as possible.

RESULTS AND DISCUSSION

Analysis of Test Samples Before Stripping Process

Visual observation of the cross section of INCONEL 939 before the stripping process can be seen in figure 3.1, it can be seen that there are 3 layers of coating on the INCONEL 939 substrate. The first layer is the top coat which has a thickness of 0.5 – 0.6 mm, the second layer is the bond coat layer which has a thickness of 0.345 – 0.373 mm, the third layer is the *interdiffusion zone* (IDZ) layer which has a thickness of 0.033 – 0.040 mm. The interdiffusion *zone (IDZ)* is formed under the *bond coat layer*. In the layer between the IDZ and the substrate a two-phase cellular region appears.

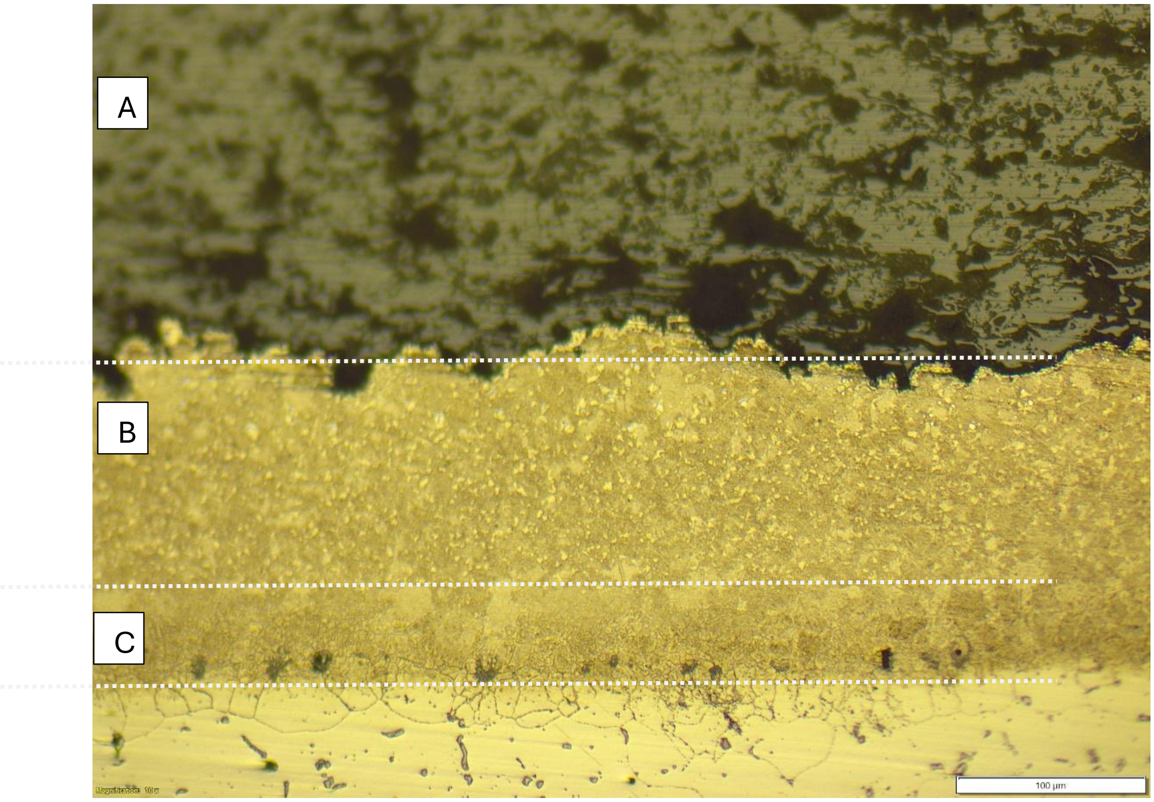

Figure 1. Thickness of the coating layer before the stripping process. a) Top coat coating, b) Bond coat coating, c) IDZ coating

Source: Authors' experimental data (2025)

It is known that in the interdiffusion zone (IDZ) layer, there is a sigma phase or topologically close-packed phase (TCP). This can be seen by the large number of these needles clustered very densely right within the IDZ area. This phenomenon is a typical sign of the TCP/Sigma phase due to interdiffusion. In the MCrAlY coating system on top of chromium-rich superalloys, this transition zone always loses its phase equilibrium due to the addition of Al from above, so that Cr is pushed out of the γ solid solution and immediately crystallizes into TCP Sigma needles. The TCP phase can be seen in Figure 3.2. The IDZ coating on *superalloys* (especially chromium-rich ones such as Inconel 939) has been filled with the accumulation of TCP phases (such as the Sigma phase) that are in the shape of sharp needles. The presence of a TCP phase that has a sharp angle in the IDZ area has the potential to act as the initial location of the crack and/or the path of the parallel of the crack, thus triggering a fatal blade fracture (Yang & Chen, 2019). If the substrate is given a new coating layer, then the layer that is already fragile and microstructurally defective remains in the layer which will result in defects during operation.

Figure 3.2 is a layer of base metal that has not been given a test treatment and then micrograph testing is carried out. From the test results, there is a carbide layer in the grain boundary area. The morphology and distribution of these carbides significantly affect the microstructural characteristics and mechanical properties of the *base metal*. Good γ′ geometry and uniform distribution of γ′ (gamma prime) particles, primary MC carbide and secondary M23C6 carbide can improve the quality of microstructures while improving the properties of these materials. Conversely, irregular shapes and uneven phase distribution can lead to degradation of microstructures. Over time, these conditions can create weak spots that are prone to crack initiation, which ultimately adversely affects the mechanical properties of the alloy (Jafarzadeh et al., 2025).

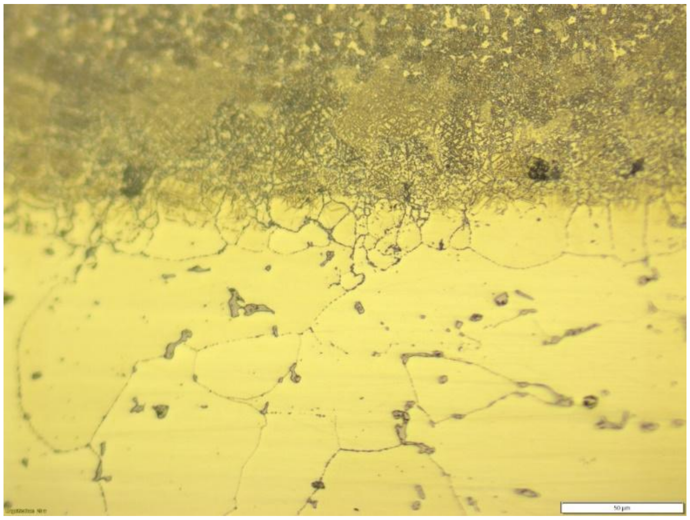

Figure 2. Interdiffusion Zone (IDZ) Layer and Grain Boundary

Source: Authors' experimental data (2025)

Comparison of Stripping Rate Results Using Grit Blasting, HCl and HCOOH

The results *of chemical cleaning* between HCl concentrations of 6 moles and 12 moles showed the difference in the speed *of the base coat stripping* process from each method. Based on the hail test metallography in table 1, the results show that the exfoliation ability of HCl concentration of 6 moles is 22.8 μm/ h and the peel yield of HCl concentration of 12 moles is 36.5 / hourμm. This difference shows that exfoliation using 12 mole HCl has a better stripping rate value.

The results *of chemical cleaning* between HCOOH with a concentration of 6 moles and 12 moles were performed a metallographic test to determine the difference in the speed *of the base coat stripping* process from each method. The results showed that the exfoliation ability of HCOOH concentration of 6 moles was 3.52 – 4.5 μm/ hour and the exfoliation yield of HCOOH concentration of 12 moles was 4.56 – 5 μm/ hour. The stripping results show that HCOOH with a liquid concentration of 6 moles or 12 moles does not have a significant difference when doing the stripping process.

The results of chemical immersion using HCl showed a much better stripping rate compared to HCOOH. From the cross section, it shows that the results of stripping using HCOOH still show the existence of a bond coat and IDZ layer on the substrate surface, while the use of HCl is able to release the base coating layer and also the IDZ layer better.

Table 1. Thickness measurement after *chemical cleaning* and stripping rate calculation

Chemical Liquids	Immersion time	Thickness before stripping (μm)	Thickness after stripping (μm)	Stripping rate (/ hour) μm
HCl 6 mol	16 hours	345 - 373	0	21,5 – 23,31
HCl 12 mol	10 Hours	345 - 373	0	34,5 – 3,73
HCOOH 6 mole	48 Hours	345 - 373	204 - 245	3,52 – 4,5
HCOOH 12 mole	48 Hours	345 - 373	126 – 133	4,56 – 5

Source: Authors' experimental data (2025)

The results of the metallography test after the stripping process on a 6 mole HCl liquid are shown in figure 3a. The results of soaking for 16 hours in 6 mole HCl liquid showed that the IDZ layer and bond coat coating on the base metal had shown perfect degradation. Figure 3b shows the condition after soaking using 12 moles HCl, perfect degradation was seen after 10 hours of soaking. 12 mole HCl has a faster immersion time, this happens because the concentration of HCl in a 12 mole solution is twice as much as compared to HCl in a 6 mole solution.

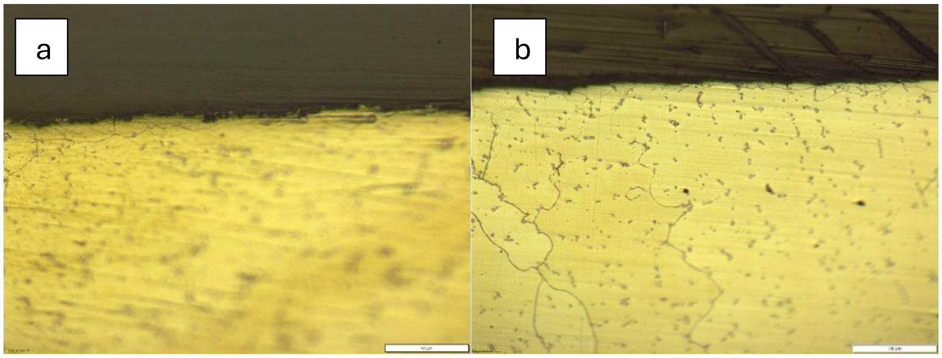

Figure 3. a) Cross section INCONEL 939 with immersion using HCl 6 mole b) HCl 12 mole

Source: Authors' experimental data (2025)

Figure 4a shows that the metalography results of the substrate after soaking with 6 mol HCOOH liquid for 48 hours showed that there was still a layer of bond coating and IDZ on the surface of the substrate. For 48 hours, the liquid is able to grade the bond coat layer as thick as 0.13 – 0.14 mm. The 12 mole HCOOH in Figure 4b shows similar performance to the 12 mole HCOOH. HCOOH 12 moles is able to perform a thickness gradation of 0.13 – 0.15 mm for 48 hours.

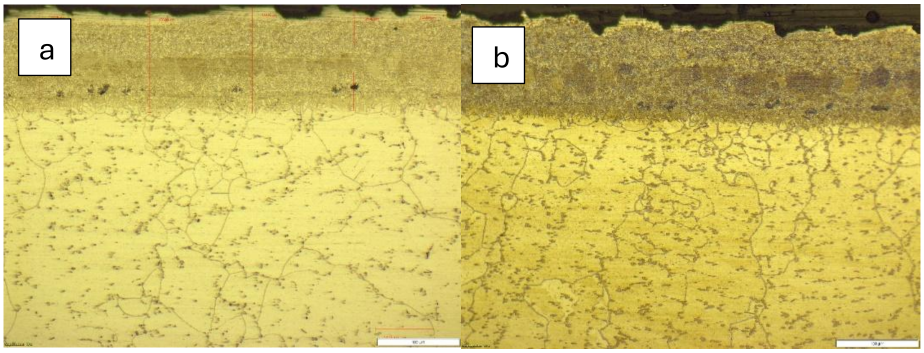

Figure 4. a) Soaking INCONEL 939 using 6 moles HCOOH b) 12 moles HCOOH
Source: Authors' experimental data (2025)

The *grit blasting* process is carried out by doing 10 cycles on a 5 x 10 cm coupon with a working time of 6 minutes. After the layer is peeled off, micrographic testing is carried out. From micrographic observation in figure 3.5, it can be seen that the remaining base coating layer is 0.009 – 0.01 mm and the IDZ layer has not experienced a thickness gradation. The results of the immersion showed a stripping rate value of 605 μm/ hour.

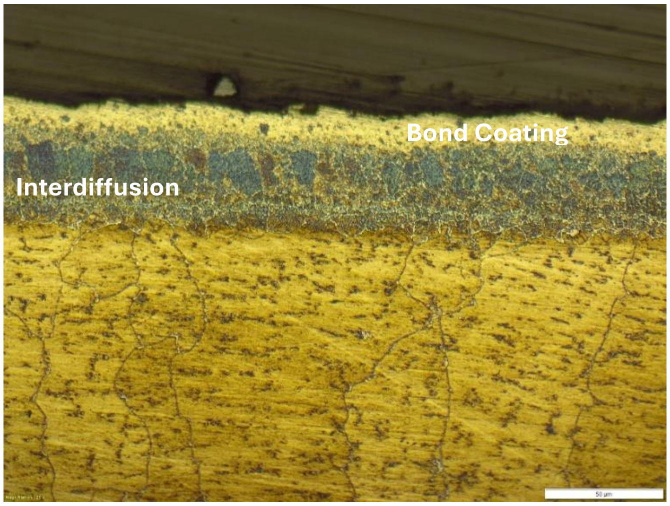

Figure 5. Thickness of the Coating Layer After Grit Blasting
Source: Authors' experimental data (2025)

To determine the rate of depletion of the coating layer, the specimen is also measured by weight before and after the blasting process. Measurements are taken on scales with an accuracy of 0.001 grams. From the weight measurement results shown in figure 6, from the graph it is known that the weight of the specimen was reduced from 110.73 grams to 102.53 grams or about 8.20 grams of the coating layer that was peeled off when soaking using HCl 6 moles for 16 hours. From the data, it was found that the stripping rate of the HCl 6 mole method was 0.51 gr/hour. Figure 7 shows a graph of the weight of the specimen when immersed using 12 moles of HCl chemical liquid, the initial weight of the specimen was 105.099 to 99.058 grams during 10 hours of immersion or 6.041 grams of peeled coating and IDZ layers. So that the stripping rate from soaking using 16 mole HCl is 0.6041 gr/hour.

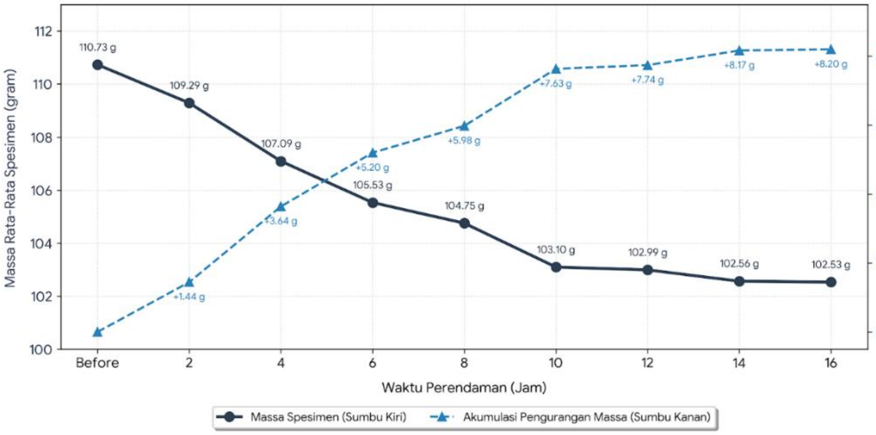

Figure 6. Specimen Weight Reduction HCl Stripping Method 6 mole

Source: Authors' experimental data (2025)

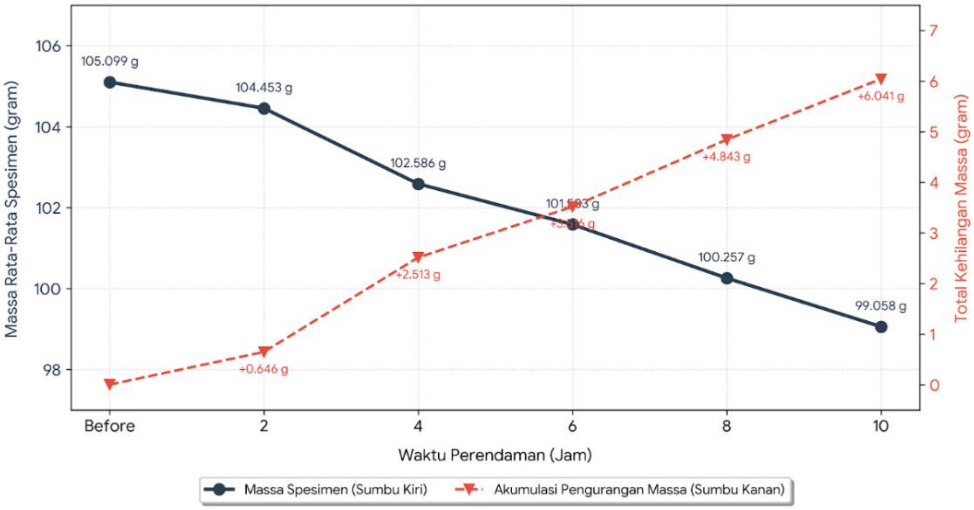

Figure 7. Specimen Weight Reduction 12 mole HCl Stripping Method

Source: Authors' experimental data (2025)

Table 2 shows the weight of INCONEL 939 specimen when the stripping method uses 6 moles of HCOOH liquid and 3 shows the weight of INCONEL 939 specimen when the stripping method uses 12 moles HCOOH fluid, both methods are performed for 48 hours. From the observations, it is known that the weight of the specimen becomes heavier and becomes not actual. This happens because HCOOH fluids tend to damage the silicon insulation layer coated on the base metal area that does not have a coating layer, so that the water layer tends to enter and fill the gap between the base metal and the silicon layer. Visualization of the silicon layer on the base coating layer is shown in Figure 8.

Table 2. Weight of the stripping method using 6 moles of HCOOH liquid

No	Time (h)	Mass (g) Average
Before With Silicon		85,535425
Before Without Silicon		78,0891
1	2	86,114675
2	4	86,42
3	8	86,820925
4	12	86,820725
5	16	86,806325
6	20	87,089825
7	24	87,20005
8	28	87,393
9	32	87,429775
10	36	87,64745
11	40	87,701275
12	44	87,875075
13	48	87,9704

Source: Authors' experimental data (2025)

Table 3. Weight of the stripping method using 12 moles of HCOOH liquid

No	Time (h)	Mass (g) Average
Before With Silicon		103,94905
Before Without Silicon		92,65305
1	2	104,244525
2	4	104,656525
3	8	104,711275
4	12	105,01405
5	16	104,58925
6	20	105,432225
7	24	105,4874
8	28	105,67795
9	32	105,777825
10	36	105,931675
11	40	106,005375
12	44	105,936675
13	48	106,244

Source: Authors' experimental data (2025)

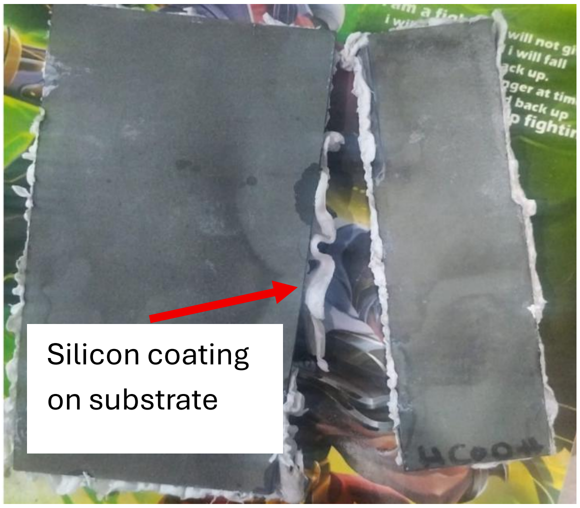

Figure 8. Silicon layer on substrate

Source: Authors' experimental data (2025)

The stripping method with grit blasting is also measured the weight of specimens before and after striping. The stripping rate performance of grit blasting is very good, which is 11 grams/hour. Although the stripping rate value of grit blasting is considered better than HCl or HCOOH, this method has a disadvantage, namely the blasting time that will change along with the area of the surface to be blasted. This is due to the blasting process which is carried out by manually directing the nozzle focused on one point on the object to be stripped (in contrast to chemical stripping which performs the stripping process evenly on each surface), so that the work cycle will take more time when carried out on a wider work area. For a specimen area of 4 x 5 cm (20 cm2), 10 cycles of processing with a time of 6 minutes are required. So that if the surface area increases, the work time will increase and vary according to the surface area that will be carried out by the stripping process.

The disadvantage of using grit blasting is also found in the homogeneity of the bond coating layer removal process. When doing the heat-in process, it can be seen that there are still many layers of coating left behind and have not been completely peeled off.

Micrography Testing

Micrograph Results of Stripping Method with HCL 6 Moles

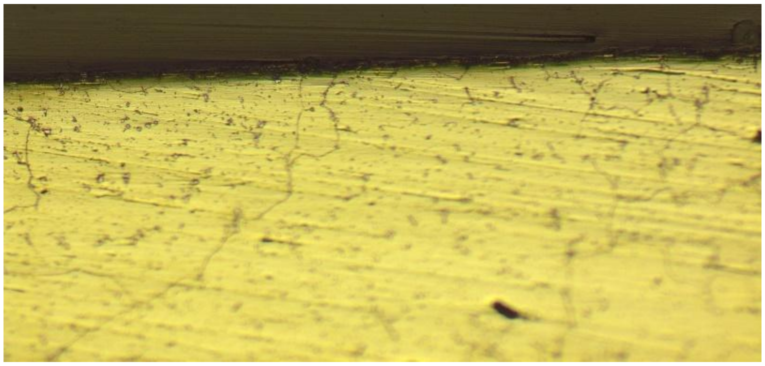

Figure 9. Cross Section Cross-Section in INCONEL 939 after immersion with HCl 6 Mol 16 h

Source: Authors' experimental data (2025)

The results of the micrograph analysis showed that the IDZ layer had completely detached. This is excellent for the subsequent coating process, as the brittle IDZ layer has been stripped perfectly.

The results of micrography testing showed that the carbides in the area around the surface did not increase in size and did not connect with each other. This separate carbide makes the structure of the grain boundary more stable.

In the grain boundary area, there is also no carbide buildup, there is no corrosiveness or change in the shape of the grain boundary. This indicates that the HCl liquid has not yet invaded the grain boundary of the substrate.

Micrograph Results of Stripping Method with HCL 12 Moles

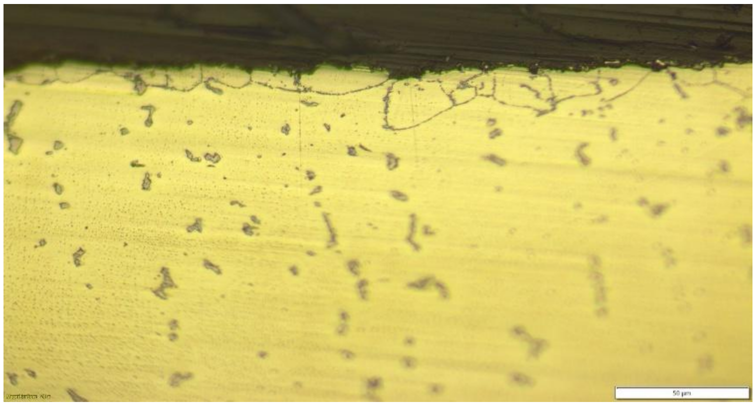

Figure 10. Cross Section Cross-Section in INCONEL 939 after soaking with HCl 12 Mol for 10 hours

Source: Authors' experimental data (2025)

The results of the micrograph analysis showed that the IDZ layer had completely detached. This is very good for the next coating process, because the brittle IDZ layer has gone through the stripping process perfectly.

The results of micrography testing showed that the carbides in the area around the surface did not increase in size and did not connect with each other. This separate carbide makes the structure of the grain boundary more stable.

In the grain boundary area shows carbide buildup, this carbide buildup can cause crack initiation when the substrate/vane is operating. Based on the visual appearance, there is no corrosion in the grain boundary area. This indicates that the HCl liquid has not yet invaded the grain boundary of the substrate.

Micrograph Testing of Striping Method With Formic Acid (HCOOH) 6 Moles

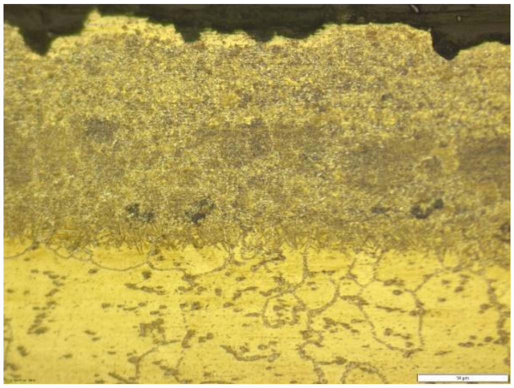

Figure 11. Cross Section Cross-Section on INCONEL 939 After Soaking with 6 mole HCOOH for 48 Hours

Source: Authors' experimental data (2025)

In the results of the micrograph analysis, it is known that there are still remaining base coating layers of 0.204 – 0.291 mm and the remaining IDZ layer ranges from 0.033 – 0.040 mm which has not been eroded evenly on all base metal surfaces. Therefore, the stripping results are considered incomplete and a follow-up process is needed to remove the remaining bond coating and IDZ layers.

Micrograph Testing of Striping Method with Formic Acid (HCOOH) 12 Moles

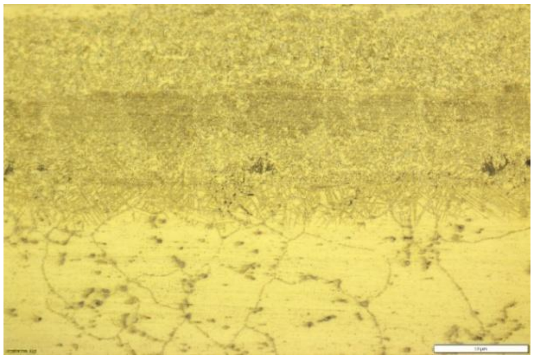

Figure 12. Cross Section Cross-Section on INCONEL 939 After Soaking with 12 Mole HCOOH for 48 Hours

Source: Authors' experimental data (2025)

In the results of micrograph analysis, it is known that there are still remaining base layers of 0.23 – 0.25 mm and the remaining IDZ layers range from 0.033 – 0.040 mm that have not been eroded evenly on all base metal surfaces. Therefore, the stripping results are considered incomplete and a follow-up process is needed to remove the remaining bond coating and IDZ layers.

Micrograph Testing of Stripping Method With Grit Blasting

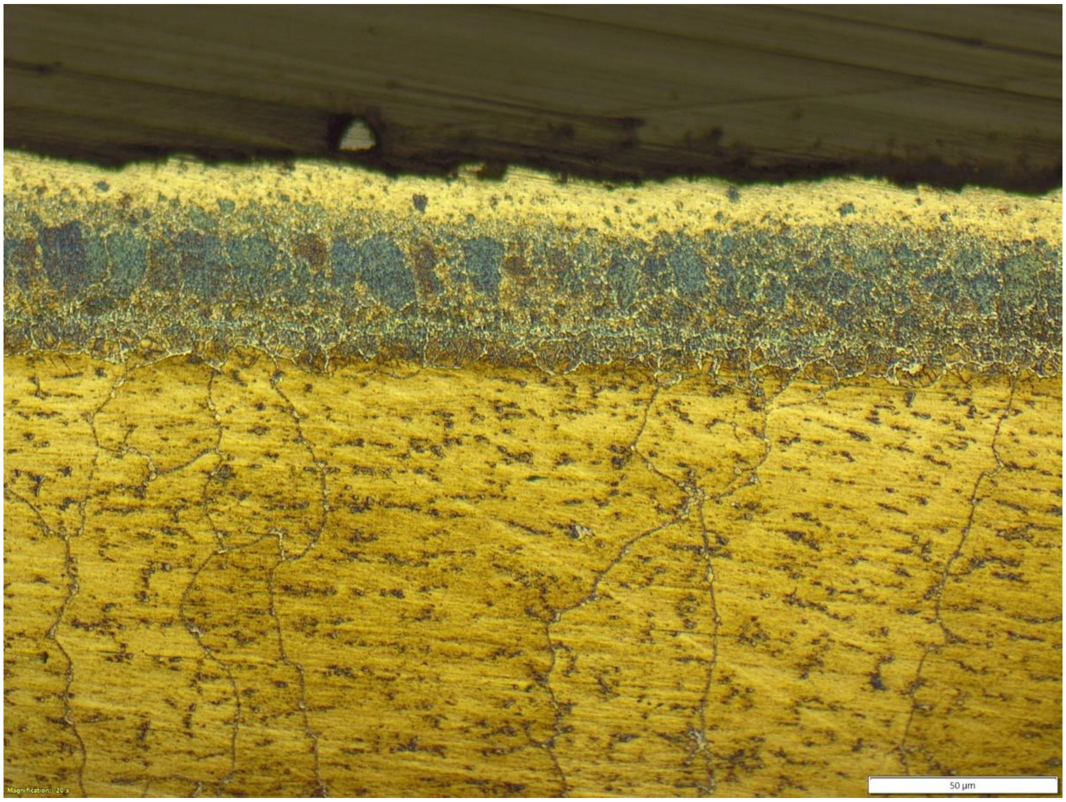

Figure 13. Cross Section Cross-Section on INCONEL 939 After Grit Blasting

Source: Authors' experimental data (2025)

After the 10-cycle process, there is still a small layer of base coat and the IDZ blm layer is perfectly eroded. There is still a layer of base coat with a thickness of 0.009 – 0.01 mm. Visually inspected after the heat-in process, the remaining coating layer spreads unevenly over the base coating area. So it is very difficult to predict how many layers are left on the base metal during the grit blasting process.

Figure 14. INCONEL 939 specimen after the heat-in process
Source: Authors' experimental data (2025)

Figure 14 shows that the color of the specimen after the heat-in process still has a gray layer, where the layer is the remaining coating layer, while the blue layer is the base metal layer. It can be seen that the remaining coating layer spreads unevenly on the base metal layer. There are layers that have been completely eroded in certain parts and there are some layers of coating that still remain.

Surface Roughness Results

The results of the analysis of 3d roughness parameters on the surface of the substrate show that the comparison of each striping process is shown in table 3.4. The table shows that the roughness value shows a value that ranges between 3 – 4 ra. This value is assumed to be safe to carry out the recoating process

Table 4. Roughness Values After Striping Process

Method	Ra Value
Blasting with aluminum oxide grit 160	4,277
Chemical stripping (HCl 6 mol)	3,334
Chemical stripping (HCl 12 mol)	3,323
Chemical stripping (HCOOH 6 mol)	7,234
Chemical stripping (HCOOH 12 mol)	7,843

Source: Authors' experimental data (2025)

Based on the measurement results, the Ra values of the stripping method using HCl fall within a better range compared to those obtained using grit blasting or HCOOH. The Ra values recorded for HCOOH stripping indicated a higher level of surface roughness. The risk associated with high Ra values is the possibility of crack initiation from the valley angles on the substrate surface. The elevated Ra values observed for HCOOH are attributed to an incomplete stripping process, resulting in uneven chemical attack on the substrate surface. In contrast, the roughness values recorded for HCl conform to the accepted standard, thereby minimising the possibility of crack initiation.

The stripping rate results showed that the grit blasting method outperformed both HCl and HCOOH in terms of processing speed. However, the superior stripping rate of grit blasting comes with a notable disadvantage: the homogeneity of coating layer removal is poor. Residual bond coat remained on the substrate surface and had not been completely removed. Furthermore, the grit blasting method was unable to fully remove the interdiffusion zone (IDZ) layer. Metallographic examination revealed residual bond coat layers of 0.009–0.01 mm in thickness and IDZ layers of 0.033–0.040 mm in thickness. These residual bond coat and IDZ layers can act as sites for residue accumulation and crack initiation. The size of the component being stripped also affects processing time; the larger the surface area, the longer the grit blasting process takes, as it is carried out manually by an operator with the nozzle concentrated on a single point at a time. This results in increased processing time as the nozzle must be traversed across the entire working surface.

The HCl stripping method yielded a better stripping rate than HCOOH, though it did not surpass that of grit blasting. Metallographic analysis confirmed that the HCl stripping method was capable of completely removing both the bond coat and IDZ layers. Following the release of these two layers, roughness analysis of the substrate after immersion in HCl yielded a value of 3.3 Ra, which falls within the recommended roughness reference range of 3–4 Ra. However, metallographic analysis of specimens immersed in 12 mol HCl revealed changes in the size of secondary carbides at the grain boundaries. Carbides that increase in size and become interconnected can render void structures unstable.

The HCOOH stripping method produced the slowest stripping rate of all three methods. This is attributable to the weak acid nature of HCOOH, which, over 48 hours of immersion, resulted in only a gradual reduction of the bond coat layer of approximately 0.13–0.24 mm. Metallographic analysis confirmed that bond coat and IDZ layers remained present, indicating that further treatment of the substrate would be required to remove them. The surface roughness values recorded exceeded the standard reference range, a consequence of the incomplete stripping process leaving the substrate surface in a rougher condition. This outcome is highly undesirable in the recoating process.

Overall, the stripping method using 6 mol HCl is recommended as the preferred approach for carrying out the stripping process. This conclusion is based on the complete removal of both the IDZ and bond coat layers, the absence of secondary carbide deformation on the substrate surface, and surface roughness values that conform to the standard reference range, requiring no further substrate surface treatment.

CONCLUSION

Based on the metallographic test results, the coating layer thickness prior to the stripping process measured 0.345–0.373 mm, with an interdiffusion zone (IDZ) of 0.033–0.040 mm. The grit blasting method achieved a faster stripping rate than both HCl and HCOOH; however, it presents a notable disadvantage in terms of coating removal homogeneity. Residual coating layers remained at several test points, necessitating an additional cleaning process after the heat-in procedure. Residual IDZ layers were also found to remain on the substrate surface. Furthermore, the processing time for grit blasting increases proportionally with the surface area to be stripped, as the nozzle can only be directed at one point at a time.

Stripping using HCl demonstrated a superior ability to remove the coating layer compared to both grit blasting and HCOOH. Both the bond coat and IDZ layers were completely removed using the HCl immersion method. However, immersion in 12 mol HCl resulted in changes to the size of the secondary carbides in the grain boundary region.

Surface roughness measurements showed that specimens treated with the HCl immersion method exhibited better surface roughness than those treated with HCOOH or grit blasting. The 6 mol HCl stripping method is considered the most optimal of the methods evaluated. This conclusion is based on several factors: the processing time for HCl is more consistent than that of grit blasting, as it is unaffected by the surface area of the coating layer; HCl achieves complete removal of both the bond coat and IDZ layers, unlike the other two methods; the stripped surface attains an appropriate roughness value; and the substrate surface exhibits no significant microstructural changes when using 6 mol HCl, in contrast to the changes observed with 12 mol HCl.

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