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Investigation of the lifetime of the coating applied on the steam turbine blade in terms of corrosion and erosion

Kaplama uygulanmış buhar türbini kanadının ömrünün korozyon ve erozyon açısından incelenmesi

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Investigation of The Lifetime of the Coating Applied on The Steam Turbine Blade in Terms of Corrosion and Erosion

Highlights

- *Change in corrosive effects on Steam Turbine Blade Coating*
- *Change in structural properties of Steam Turbine Blade Coating*
- *Change in erosive properties of Steam Turbine Blade Coating*

Graphical Abstract

Detailed examination images of the abrasion damage of the used turbine blade are given in Figure X. When the photos are examined, it is seen that the coating in the upper part of the blade (A and B) decreases until the transition coating almost disappears; on the other hand, it is more present in the blade tip part (C). This situation shows that corrosion and wear have a more severe effect on the blade surface (upper) parts.

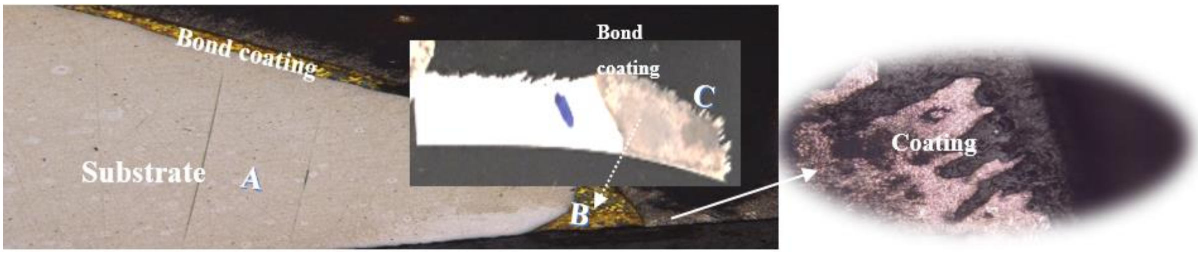

Figure 1. Images of the cross-sectional macrostructure and microstructure of the used sample

Aim

This study aims to evaluate the physical and chemical changes that turbine blades are exposed to under operating conditions and their effects on the material.

Design & Methodology

In the experimental study, chemical and dimensional measurements, optical microscopy, SEM, and EDS measurements were performed after metallographic preparation of the samples. Structural analysis was performed using XRD, and hardness tests were conducted to determine the samples' mechanical properties and lifespan.

Originality

In this unprecedented study, the amount of corrosion and wear that occurred during the durability/operational life of a turbine blade and its coating, which had been used for 25 years in a Thermal Power Plant, was comparatively examined with an original turbine blade made of the same material that had never been used.

Findings

A significant decrease in mechanical properties was observed in the turbine blade coating. In steam turbines, corrosion and erosion have been observed to occur separately and/or together under the influence of high temperature and pressure

Conclusion

It was determined that the steel used in the steam turbine was AISI 420 stainless steel, and the coating applied to the blade was a wear-resistant Co-Cr alloy coating. In the used turbine blade coating, about 10% to 30% thickness reduction was observed regionally, not more than the area most touched by the steam. In addition, in the mechanical tests conducted, a decrease of approximately 10% was detected in the hardness tests performed on the used blade and the unused blade.

Declaration of Ethical Standards

The authors of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

Investigation of The Lifetime of the Coating Applied on The Steam Turbine Blade in Terms of Corrosion and Erosion

(Bu çalışma ICMATSE 2024 konferansında sunulmuştur. / This study was presented at ICMATSE 2024 conference.)

Araştırma Makalesi / Research Article

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ABSTRACT

This study evaluated the physical and chemical changes that turbine blades are exposed to under operating conditions and their effects on the material. Within the scope of the study, the amount of corrosion and wear that occurred during the durability/operational life of a turbine blade and its coating used for 25 years in a Thermal Power Plant, and an original turbine blade made of the same material that has never been used were comparatively examined. This research contains significant findings in evaluating the suitability of the existing material and coating for the longer life of turbine blades and obtaining ideas for changes to be made to the coating in terms of resistance to physical and chemical conditions. The turbine blade examined in the study was determined to be coated with Co-based material (containing Cr, Mo, Ni, Mn) using the thermal metal spray coating method. AgCuZn-based bond coating was applied to the coating and the substrate. After 25 years of service with an average energy production of 69,466,700 MWh, the turbine blade was removed from the turbine and examined for corrosion and erosion damage analysis. In the experimental study, chemical and dimensional measurements, optical microscopy, SEM, and EDS measurements were carried out due to the metallographic preparation of the samples. XRD performed structural analysis, and hardness testing was used to determine the mechanical properties and life of the samples. As a result of the investigations, it was determined that the turbine blade was subjected to corrosion, erosion, and corrosive erosion; the coating on the surface was completely worn locally, and there was a cross-sectional reduction due to wear (corrosive and erosive) at the blade tips. The coated parts were more resistant to erosive and corrosive effects. When comparing the coating wear with the base material wear, the level of wear is more clearly seen in the transition area between the coated area and the base material.. It has been observed that corrosion and erosion cause abrasion together.

Keywords: Steam turbine blade, Erosion, Corrosion, Materials Characterization

Kaplama Uygulanmış Buhar Türbini Kanadının Ömrünün Korozyon ve Erozyon Açısından İncelenmesi

ÖZ

Bu çalışmada, türbin kanatlarının işletme koşulları altında maruz kaldığı fiziksel ve kimyasal değişimler ve bunların malzeme üzerindeki etkileri değerlendirilmiştir. Çalışma kapsamında, bir Termik Santralde 25 yıl kullanılmış bir türbin kanadı ve kaplamasının dayanıklılık/işletme ömrü boyunca oluşan korozyon ve aşınma miktarı ile aynı malzemeden yapılmış hiç kullanılmamış orijinal bir türbin kanadı karşılaştırmalı olarak incelenmiştir. Yapılan bu araştırmada, türbin kanatlarının daha uzun ömürlü olabilmesi amacıyla mevcut malzeme ve kaplamanın ne derece uygun olduğunun değerlendirilmesi ve fiziksel ve kimyasal koşullara dayanıklılık konusunda kaplama üzerinde yapılacak değişiklikler için fikir edinilebilmesi açısından önemli bulgular içermektedir. Çalışmada incelenen türbin kanatçığının termal metal püskürtme kaplama yöntemi ile Co esaslı malzeme (Cr, Mo, Ni, Mn içeren) ile kaplandığı belirlenmiştir. Kaplama ile altlık arasına AgCuZn esaslı bağlama kaplaması uygulanmıştır. Ortalama 69.466.700 MWh enerji üretimi ile 25 yıllık hizmet sonrasında türbin kanatçığı türbinden sökülerek korozyon ve erozyon özellikleri incelenmiştir. Deneysel çalışmada, numunelerin metalografik hazırlanması sonucunda kimyasal ve boyutsal ölçümler, optik mikroskopi, SEM ve EDS ölçümleri yapılmıştır. XRD ile yapısal analiz yapılmış, numunelerin mekanik özellikleri ve ömürleri belirlemek için sertlik testleri yapılmıştır. Yapılan incelemeler sonucunda; türbin kanadının hem korozyon ve erozyona hem de korozif erozyona maruz kaldığı, yüzeydeki kaplamanın lokal olarak tamamen aşındığı, kanat uçlarında aşınma (korozif ve erozif) nedeniyle kesit daralması olduğu tespit edilmiştir. Kaplama yapılan kısımların erozyon ve korozif etkilere karşı daha dayanıklı olduğu görülmüştür. Kaplama aşınmasının taban malzeme aşınmasıyla kıyaslamasında kaplama yapılan bölge ile ana malzemenin geçiş bölgesinde aşınmanın düzeyi daha açık görülmektedir.. Korozyon ve erozyon etkilerinin birlikte aşınma etkisine neden olduğu görülmüştür.

Anahtar Kelimeler: Buhar türbini kanadı, Erozyon, Korozyon, Malzeme karakterizasyonu

1. INTRODUCTION

Investigating the life of coatings applied to steam turbine blades is crucial in the power generation sector. Steam turbines are critical components that directly affect the efficiency and reliability of power plants. The blades of these turbines are exposed to corrosive effects such as corrosion and erosion while operating under high temperatures and pressures. Therefore, the durability and

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performance of coatings are vital to extend the life of turbines and reduce maintenance costs. The motivation of this study is to increase sustainability in power generation and maximize the operational efficiency of turbines [1,2]. Literature studies on corrosion and erosion resistance of coatings applied to steam turbine blades are limited. In particular, sufficient data on coatings' long-term performance and lifespan have not been encountered. This study aims to fill this scientific gap by examining how coatings behave under different operating conditions and which factors affect coating life. This will contribute to developing more durable and long-lasting coating materials in the energy sector [3,4]. Steam turbines are equipment used in thermal power plants such as coal, natural gas, and nuclear power plants. They convert the thermal energy of a fluid with high thermal energy, i.e., high temperature and pressure, into mechanical energy. Water vapor is used as the fluid, and the resulting mechanical energy is usually converted into electrical energy with the help of a generator [5,6]. Many moving and stationary blades on a steam turbine are designed to direct the steam flow and transfer power. Although the blades are manufactured from high-quality stainless steel with special manufacturing methods, they are often at risk of erosion and corrosion [6]. In materials science, erosion describes mechanical damage caused by high-velocity impacts. Erosion usually occurs due to solid/solid or liquid/solid or gas/solid interactions. Another definition defines erosion as the gradual loss of original material due to the mechanical interaction between a solid surface and a multicomponent fluid or impinging liquid or solid particles. [7,8] There are different types of erosion, such as solid particle erosion, cavitation erosion, liquid impact erosion, and cyclic erosion [7]. Solid particle erosion is a vital material degradation mechanism encountered in several engineering systems, such as thermal power plants, aircraft gas turbine engines, pneumatic mass transportation systems, coal liquefaction/gasification plants, and ore or coal slurry pipelines [9- 11]. Solid particle erosion causes availability reductions in power plants, increased unplanned maintenance rates, increased fuel consumption, and significant problems in aviation, such as serious turbine engine failures [12-19]. Although it seems simple, the erosion process is much more complex. After the plastic deformation that occurs in the form of a very shallow/thin layer due to solid or liquid impact on the surface of the metal material, metal loss occurs in the form of particles breaking off from the surface. In the early stages of erosion, while the first

Plastic deformation occurs, and symptoms are observed when erosion is not fast or very low. After this initial damage, wear begins at the weakest points [20]. Sudden cross-section changes or material wall edges are the areas where erosion damage is clearly observed. As a result of cross-section changes and high-pressure flow or water penetration at the ends, erosion craters are usually formed. This crater's sharp corners lead to the formation of narrow pits or lower tunnels. This situation is seen in Figure 1. After creating these pits, the real destructive wear will occur, and wear will continue as larger pieces break off. If the first wear crater has a flat surface, the wear rate will be lower [9,21].

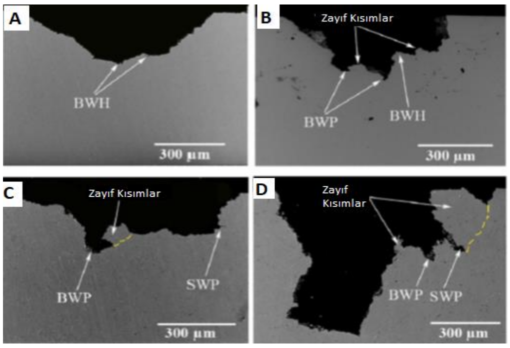

Figure 1. SEM image of the initial flat and ridged surface characteristic of erosion damage [9] [icmatse2024]

Material erosion, the effect of surface roughness on erosion, and long erosion formations using low-impact velocities (<100m/s) were investigated [24]. After several thousand impacts, numerous depressions were observed on the surface of the attacked copper. Such localized material flow and surface roughness were suggested as the main reason for the onset of material loss. It was evaluated that pits on the material surface and the resulting material loss were formed due to the effect of the high-speed fluid flowing on the surface. The coatings applied to the turbine blades have been determined to be a serious protection against erosion and corrosion [25-27]. Erosion is caused by the mechanical interaction between the material surface and steam at high temperatures and pressures. Erosion, which is visually evident as material loss, especially at the blade tips, is metal loss due to the impact of liquids or solids. Attack is promoted by turbulent, high-velocity fluid flow [28]. Rapid pressure changes promote shock waves and turbulence. Sudden changes in flow direction and entrainment of solid particulate matter in the fluid also contribute to erosion. Turbulence is also caused by a change in flow direction, a sudden change in cross-section, a thick deposit of sediment, or the presence of an obstruction that disrupts the flow. Although several factors affect the formation of deposits on turbine components, the general effect is the same regardless of the cause. Adherent deposits form in the steam passage and distort the original shape of the turbine blades [29]. These deposits, which are usually rough or irregular on the surface, increase resistance to the steam flow. The disruption of the steam passages alters steam velocities and pressure drops, reducing the capacity and efficiency of the turbine. In severe conditions, deposits can cause excessive rotor thrust. Irregular accumulation causes vibration problems by disrupting the balance of the turbine rotor [30]. In studies of solid particle erosion dating back a century, it was thought that the effects of erosion on turbine blades could be reduced by coating the blades, and significant decreases in the impact of erosion were demonstrated [27,28,29]. In the first applied coatings, the desired results could not be achieved due to the low toughness rate of the coating layer and the high internal stress rates [30,31,32]. Material erosion, the effect of surface roughness on erosion, and long erosion formations using low-impact velocities (<100m/s) were investigated [24]. After several thousand impacts, numerous depressions were observed on the surface of the attacked copper. Such localized material flow and surface roughness were suggested as the main reason for the onset of material loss. It was evaluated that the formation of pits on the material surface and the resulting material loss were due to the effect of the high-speed fluid flowing on the surface. The coatings applied to the turbine blades have been determined to be a serious protection against erosion and corrosion [25-27]. When the studies on this subject are examined, they aimed to obtain surface protection for steam turbine blades with different coating techniques and metal-ceramic powders [33,34,35]. In this study, the erosive and corrosive properties of the coating applied to the turbine blade that we will examine during its 25-year operation period will be discussed. Different studies in this field explore the effects of coating, coating methods, and laboratory test data on wear and corrosion resistance. However, there is no real case study. This study aims to investigate and discuss the resistance of the coating made on a turbine blade sample used during a 25-year operating period against abrasive and corrosive effects, the components formed as a result of wear, the type of wear, and the level of damage in terms of determining the resistance, which has never been done before in the literature.

This study aims to evaluate the physical and chemical changes that turbine blades are exposed to under operating conditions and their effects on the material, and to evaluate the changes that can be made to the coating according to different operating conditions by extracting the differences between the blade that has worked for a long time and the blade that has never worked.

2. MATERIAL and METHOD

In this study, the amount of corrosion and abrasion in the strength/operational life of a turbine blade used in a Thermal Power Plant was investigated, and the case was analyzed. The original unused turbine blade material and areas with the same coating were compared. The turbine blade examined in the study was determined to be coated with Co-based material (containing Cr, Mo, Ni, and Mn) using the thermal metal spray coating method. AgCuZn-based bond coating was applied between the coating and the substrate. After 25 years of service with an average energy production of 69.466.700 MWh, the turbine blade was removed from the turbine and examined for corrosion and erosion damage analysis. In the experimental study, chemical and dimensional measurements, optical microscopy, SEM, and EDS measurements were carried out due to the metallographic preparation of the samples. XRD performed structural analysis, and hardness and wear inverses were used to determine the mechanical properties and life of the samples. Chemical analysis, SEM, EDS, XRD, micro and macrostructure studies, dimensional measurements, and surface damages on the coating and base material were performed on a low-pressure steam turbine blade of a thermal steam turbine that has been used in a thermal power plant and an unused steam turbine blade (Figure 2). Hardness tests were performed on samples from used and unused turbine blades, five regions from the substrate, and three regions (1, 2, and 3) from the coating region (Figure 3). Hardness measurements were taken using a load of 11,5 mJ on a Proceq Eqoa Tip 3 brand device. X-ray diffraction (XRD) analyses were performed on a Bruker D8 Advance device. Monochromatic Cu Kα radiation (λ= 1.54056 Å) was used at 40kV and 40 mA operating conditions, 10-90 angle range, and 0.04 degree/min scan rate.

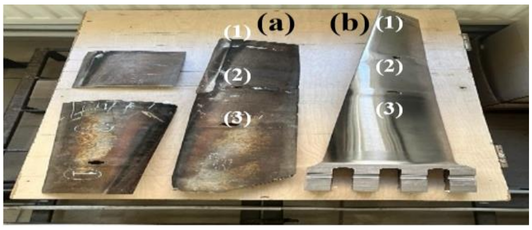

Figure 2. Used (a) and unused (b) steam turbine blades [icmatse2024]

It is seen that the intermediate coating is 0.3-0.4 mm thick on average. The coating is: 2-4 mm on the back in region B, 4-5 mm on the tip, and 15-16 mm wide, 4-5 mm thick on the tip, and 7-8 mm wide on the tip in region C. Since sample A is an uncoated area, the shoulder tip of the wing has been primarily worn, and the thickness has decreased by 25%. Since the steam intensity is higher in region B, the coating tip has been worn by 10%. In region C, where the most severe steam effect is seen, 20-30% wear has occurred both on the shoulder tip and back of the coating and on the uncoated parts (Figure 4,5). Since the hardness was measured from the area where the coating remained on the used blade, measurements were made from the exact location on the other side. The results showed that ASTM A276 values should be in annealed AISI 420-quality stainless steel used as the blade material [36]. This study was conducted as a comparative analysis of turbine blades used and unused for comparison purposes. When the chemical analysis results were evaluated, it was determined that the primary materials of the turbine blade were very much the same. This approach is essential for the reliability of other data obtained in the study. On the other hand, the transition and primary coating data also gave similar results.

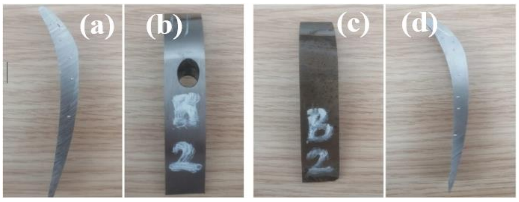

Figure 3. Images of unused (a and b) and used (c and d) turbine blade hardness test samples

Figure 4. The turbine blade that has completed its working life, and the areas from which samples are taken

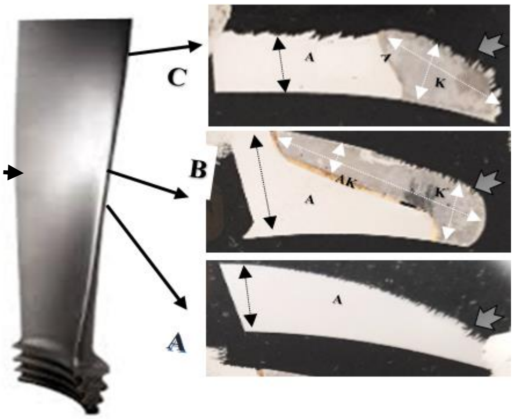

Figure 5. Sectional images of the samples taken (K: Coating, A: Base, AK: Intermediate coating)

3. EXPERIMENTAL RESULTS AND DISCUSSIONS

First, a chemical analysis of the used and unused turbine blade material was performed. As a result of the study made with the sample taken from the turbine blade area, it was determined that the material was AISI 420-quality stainless steel (Table 1). The results of the chemical analysis performed on the unused turbine blade coating area are given in Table 2. It was observed that the coating was a CoCr-based coating. In particular, the aim was to reduce wear by using Co and Cr. The hardness measurement results of both blade materials were evaluated (Table 3).

On the other hand, when the coating hardness was measured, it was determined that the hardness of the unused material was higher than that of the used one. The coating of the used blade weakens over time due to the effects of wear and corrosion, and it completely disappears at the end of its service life. These results explain the process of the coating first weakening (decrease in hardness) and then completely disappearing due to the effects of corrosion and/or other wear mechanisms during the use of the blade material [37]. A study observed that corrosion and erosion on turbine blades caused a severe decrease and deterioration in the material's mechanical properties [43]. Detailed examination images of the abrasion damage of the used turbine blade are given in Figure 6. When the photos are examined, it is seen that the coating in the upper part of the blade (A and B) decreases until the transition coating almost disappears; on the other hand, it is more present in the blade tip part (C). This situation shows that corrosion and wear have a more severe effect on the blade surface (upper) parts. Although such findings are not shown in the literature [37], it is shown that the wear intensity increases on large surfaces. Because steam and abrasives hit the blade surfaces more, the turbine is rotated. This situation is also directly proportional to the increase in surface area for corrosion

and wear on large and flat surfaces. In the tests carried out in the laboratory environment, erosion was observed on the turbine blades where the same operating conditions were created. The research also compared the resistance of several different types of coatings against corrosive and erosive effects. [44].

Defects in the form of irregularities and gaps in the thickness were detected in the intermediate coating. It is seen that the intermediate layer is 0.3-0.4 mm thick on average. The coating thickness is 2-4 mm on the back in region B, 4-5 mm on the tip, and 15-16 mm wide, 4-5 mm thick on the tip, and 7-8 mm wide on the tip in region C. Since sample A is an uncoated area, the shoulder tip of the blade has been primarily worn, and the thickness has decreased by 25%. Since the steam intensity is higher in region B, the coating tip has been worn by 10%.

In region C, where the most severe steam effect is seen, 20-30% wear has occurred both on the shoulder tip and back of the coating and on the uncoated parts [37].

Table 1. Chemical analysis of used and unused türbine blades

	C	Si	S	P	Mn	C
420 stainless steel	0.16-0.25	≤1.00	≤0.015	≤0.040	≤1.50	12.00-14.00
Used Blade	0.22	0.27	0.008	0.020	0.30	12.50
Unused Blade	0.21	0.78	0.005	0.07	0.51	12.80

Table 2. Chemical analysis of coating materials

	Co	Cr	W	Si	Fe	Mn	Ni	Mo	C
Stellite 6	Bal.	27.00-33.00	3.00-6.00	≤1.50	≤3.00	≤1.00	≤3.00	0.50-2.00	0.90-1.40
Coating (Unused)	61.78	28.92	4.05	1.33	1.30	1.00	0.80	0.73	1-1.10

The blade used for the microstructures, SEM images, and EDS analysis of sample A is given in Figure 7. The photos and Analyses show a turbine blade structure with a three-layer (base, bond coating, and top coating) structure consisting of three different materials (420 stainless steel, hard solder, and Co-based). When looking at sample A (Figure 5), it is seen that there is no coating on the surface since this area has never been coated before; only the resistance of the substrate material to the working conditions is seen; a high rate of wear occurs during the working process; and chemical changes occur on the surfaces during the working process. The results of the chemical analysis show that the substrate material is AISI 420 stainless steel, various unstable oxides occur on the uppermost parts of the worn surfaces, and the wear occurs much more severely inward in the form of a line parallel to the steam direction along the grain boundaries. The particles that emerge due to the wear cause more severe wear of the general system and the turbine blades by causing a particle effect [38].

Table 3. Hardness of unused and used specimens

Measurement area	Unused (HRc)	Used (HRc)
Substrate 1	21.3	
Substrate 2	26.5	
Substrate 3	26.0	
Substrate 4	26.5	
Substrate 5	24.2	
Coating 1	43.7	41.9
Coating 2	43.4	40.3
Coating 3	46.7	41.7

Figures 8-10 show that macro- and microstructural analysis, SEM images, and EDS analysis of sample B were used. The pictures and studies show that the turbine blade structure has a three-layer (substrate, bond coating, and coating) structure consisting of three different materials (AISI 420 stainless steel, hard solder, and Co-based) (Figure 9-10). Bond coating application is common for a better fit and adhesion/bonding resistance during coating processes. In this blade, Cu-based intermediate bond coating is applied, and it is seen that it is coated with Co-based superalloy material [38].

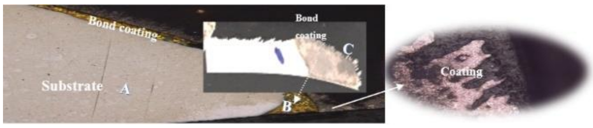

Figure 6. Images of the cross-sectional macrostructure and microstructure of the used sample [icmatse2024]

Figures 11-13 show the macro and microstructure images and chemical analysis data obtained from sample C. It was observed that very severe wear occurred both on the blade shoulder tip coating and on the back of the substrate (Figure 11-12). Irregularity and void-shaped defects were detected in the bond coating thickness. The coating has a dendritic structure, and much segregation was observed (Figure 13). Segregation is a point and/or regional composition difference. Thus, the corrosion potential increases in a structure with segregation. In sample C, the most severe wear occurred due to the steam's chemical and mechanical effects (Figure 13.a-c). Figure 12 shows the linear elemental EDS analysis to determine the chemical transition and bonding properties between the bond coating and the coating. When the analysis results are examined, it is understood that there are partial transitions between the bond coating and the coating regions. Therefore, the bond between both coatings is strong, and there will be no separation/, breakage/shedding while using the blades [39].

The bond coating is silver welding or hard soldering (barzing). In many applications, it is preferred as a bonding/joining or transition material between incompatible materials [40]. It contains mainly Cu, Ag, and Zn elements and has a low melting temperature and high wetting/coating ability. The surface coating is abrasive/adhesive/corrosive wear-resistant Co, Cr-based coating material. It is the coating material type preferred, especially in high-temperature environments, in such materials [41].

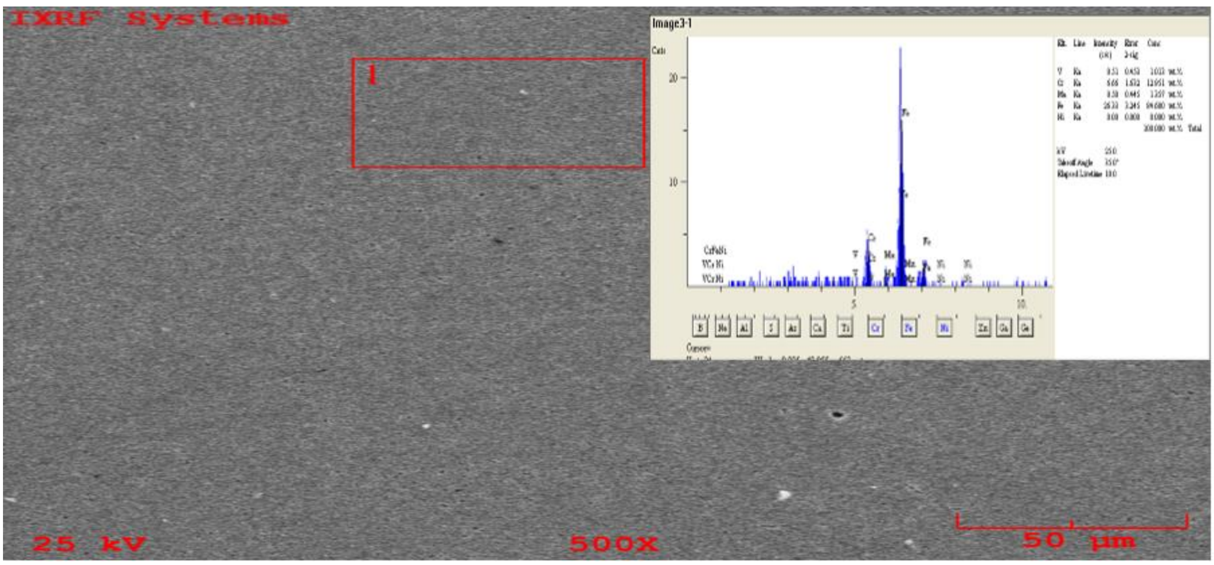

Figure 7. SEM-EDS analysis of the transition regions of sample A

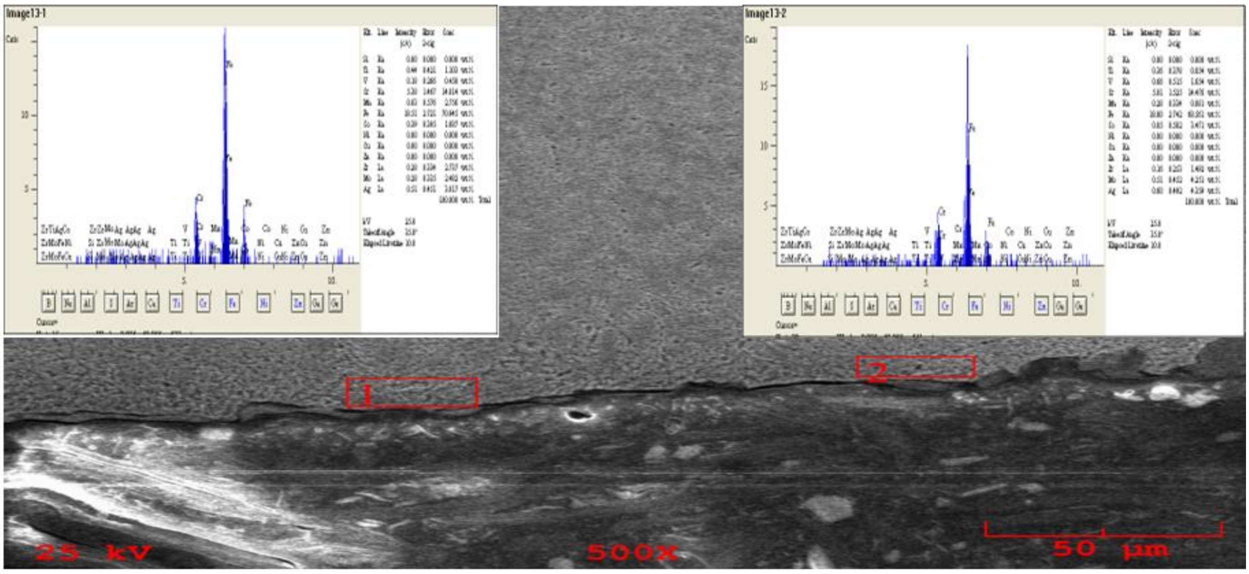

Figure 8. Macrostructure images of sample B

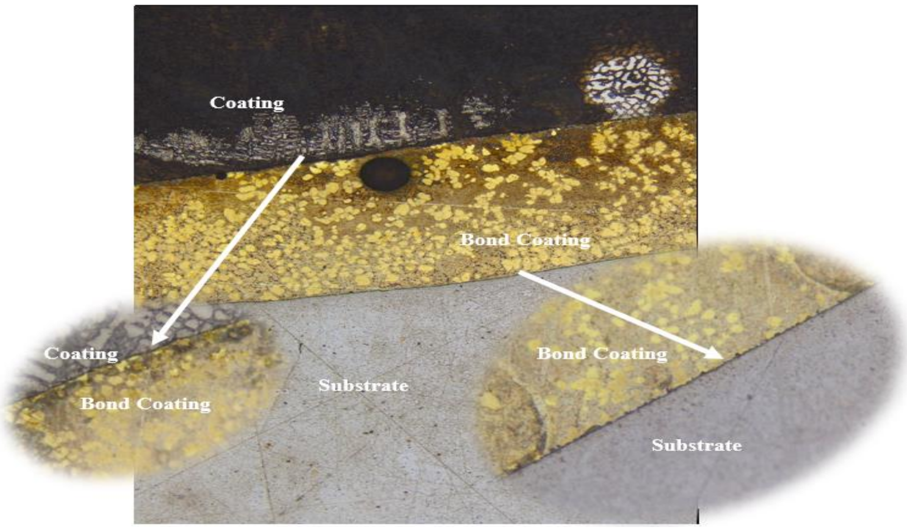

Figure 9. SEM image and EDS analysis of the substrate of sample B.

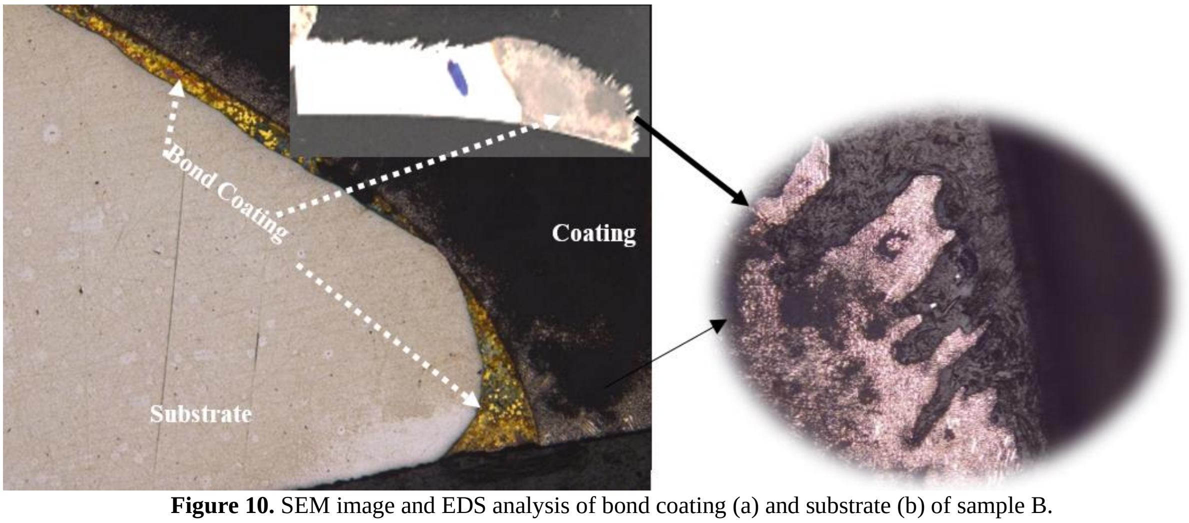

Figure 10. SEM image and EDS analysis of bond coating (a) and substrate (b) of sample B.

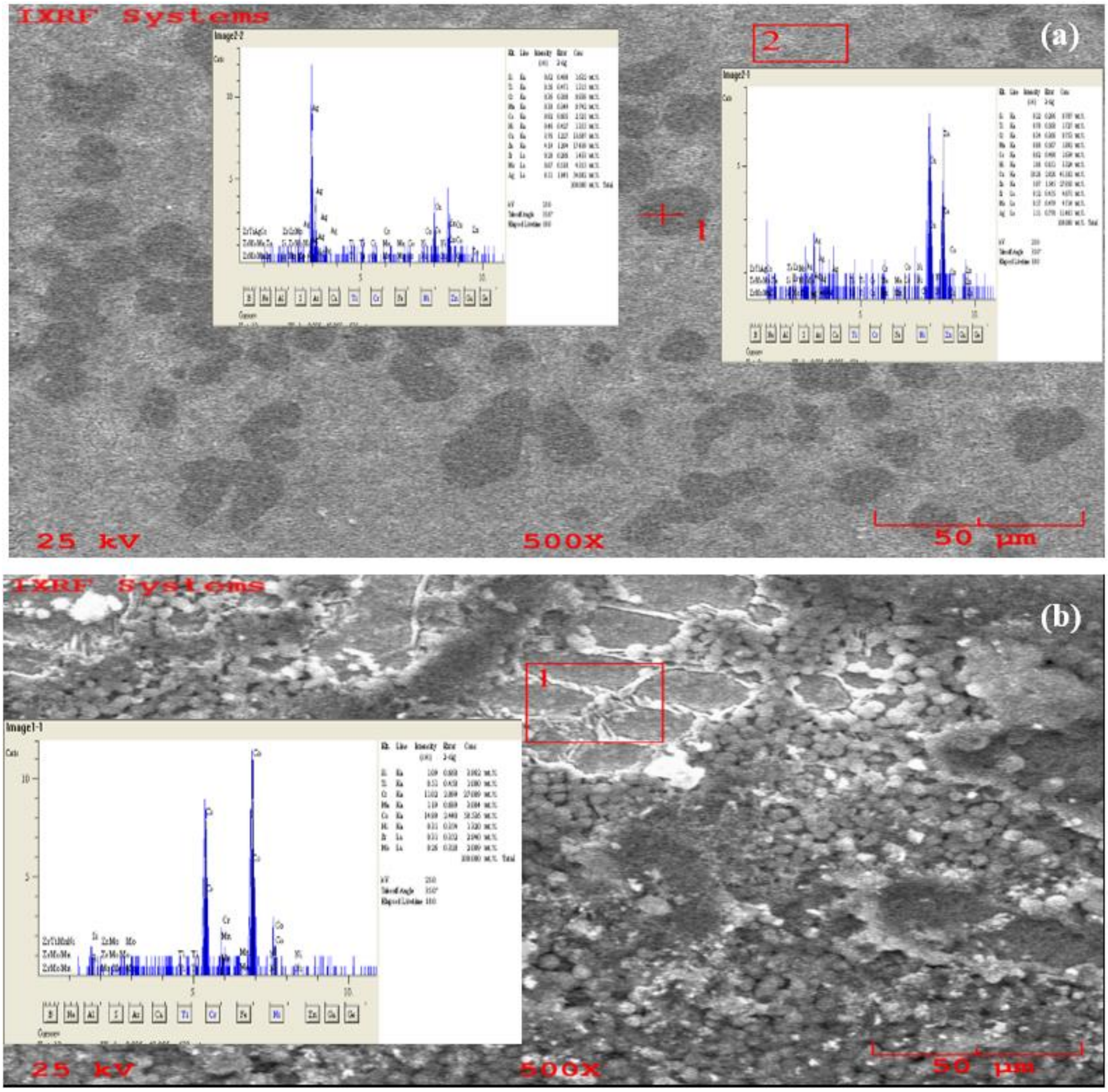

Figure 11. Macrostructure images of sample C

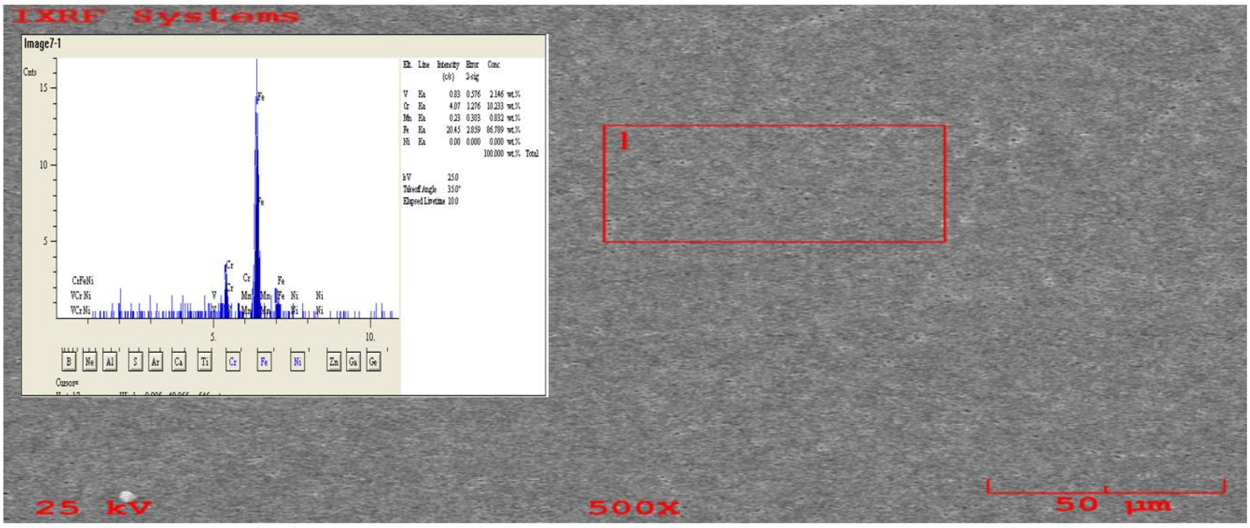

Figure 12. SEM image and EDS analysis of the substrate of sample C.

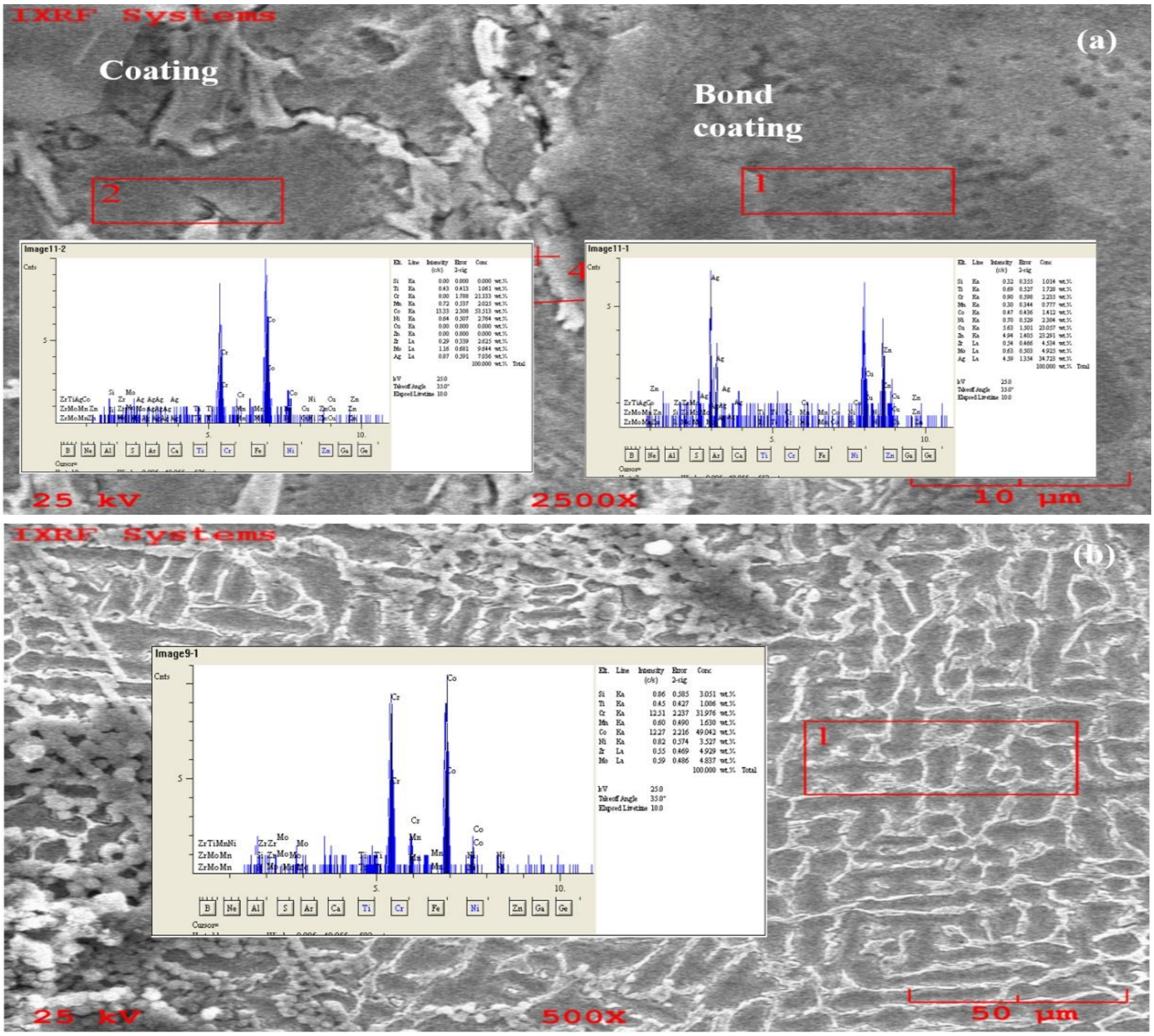

Figure 13. SEM image and EDS analysis of bond coating (a) and coating (b) of sample C.

They are preferred due to both high-temperature wear and corrosion resistance. The corrosion products formed were determined by XRD analysis of A, B, and C surface samples (Figure 15). It was determined that oxides of the elements comprising the substrate were formed in sample A, and the coating material in samples B and C. The formation of chemically and mechanically stable oxides at high temperatures in the coating and substrate surface will provide surface passivation and protection. However, the corrosion + abrasive wear process continued since very mixed oxides were formed here and there was a continuous mechanical abrasion effect, the corrosion + abrasive wear process continued. All three region examinations showed that the substrate/blade material has a classic AISI 420-quality stainless steel composition and coaxial grain structure. The coating is applied mainly in areas where abrasion is severe. The bond coating is applied first, and then the main coating is applied. It has been determined that the bond coating and main coating structures are suitable, and the interface between them is sufficient. This is a standard application in such fins [36]. This application is necessary to improve the wear and corrosion properties at high temperatures. However, as can be seen from this study, although the Co-Cr coating materials are very resistant to corrosion, it is clearly understood from the oxidized compounds that the coating material reacts with the oxygen in the environment after a specific period of time, primarily due to the catalytic effect of high temperatures, and therefore corrodes (Figure 15). When the difference between the A, B, and C samples is evaluated, the components belonging to the coating material are dominant in sample A, while the oxides of the elements belonging to the bond coating material and the components belonging to the base (fin) material are dominant in samples B and C. This situation is critical in revealing the lower parts with the wear of the corroded surfaces and showing how the process progresses in the progressive corrosion and wear processes. This study shows that using more stable materials (oxide, carbide, and nitride) in blade coatings would be appropriate for these blades [42,45].

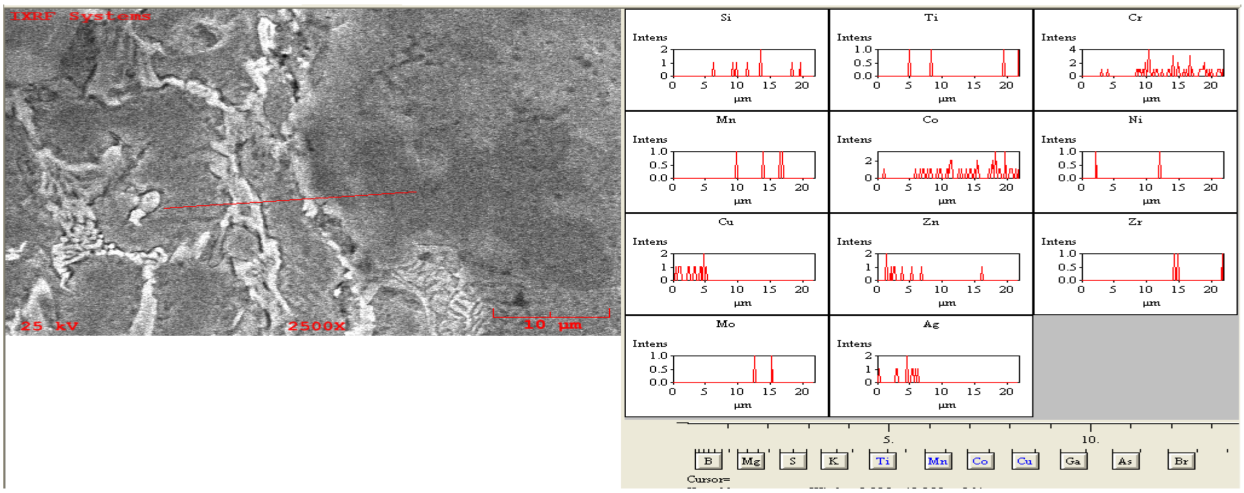

Figure 14. Sample C bond coating and coating SEM image and transition region linear EDS analysis

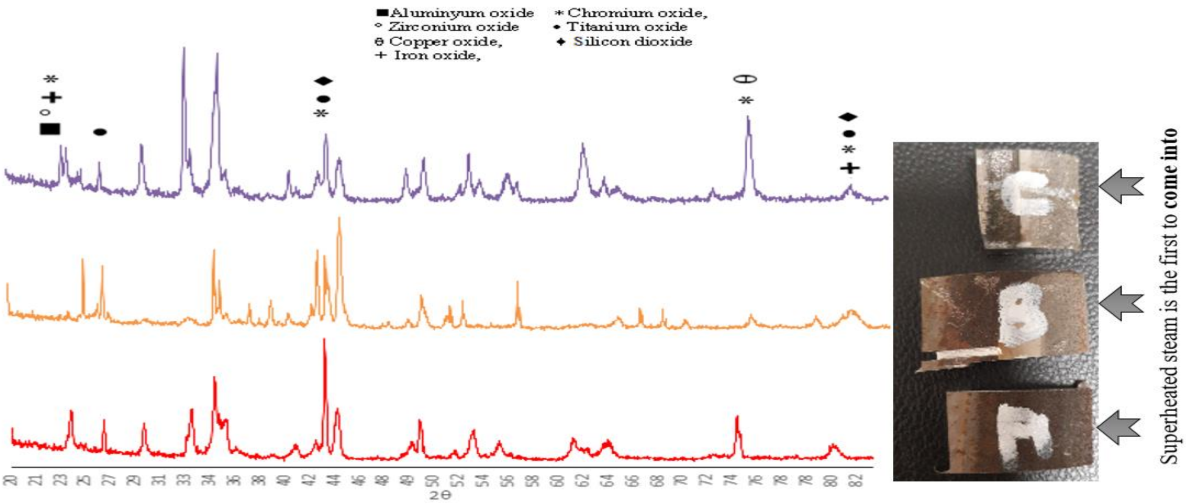

Figure 15. XRD results obtained from sample surfaces and the resulting products (A, B, and C).

4. RESULTS (CONCLUSION)

As a result of the tests and research determined that the steel used in the steam turbine was AISI 420 stainless steel, and the coating applied to the blade was a wear-resistant CoCr alloy coating. A 10% to 30% thickness reduction was observed regionally in the used turbine blade coating, not more than the area most touched by the steam. In addition, in the mechanical tests conducted, a decrease of approximately 10% was detected in the hardness tests performed on the used blade and the unused blade.

In addition to these;

After the structural examination and analysis of the steam turbine blade that was scrapped after 25 years of use,

- In steam turbines, corrosion and erosion have been observed to occur separately and/or together under the influence of high temperature and pressure.,
- In steam turbine blades, especially the areas where the effects of high-temperature steam are high (the shoulder and upper shoulder part), must be coated,
- Shock-intensive and destructive wear occurs on the uncoated base material, and as a result, the blade shoulder part becomes 65% thinner,
- During the coating process, an intermediate bonding coating is made using a Cu-based hard solder material, and there are defects in the form of voids in this coating.
- The main coating is a Co-based superalloy material, but despite this, it is subject to corrosion and erosion wear.
- The structure of the coating contains dendritic and segregations, which accelerate the formation of corrosion,
- Wear is high because the compounds formed by the elements in the coating structure in the corrosive environment do not allow the formation of a stable surface layer.
- The coating structure should be produced in a homogeneous composition and without segregation,

- It has been determined that oxidation in the final coating after bond coating should form a stable surface layer.
- Erosion in heavy equipment and components, such as turbines rotating at high temperatures and pressure, cannot be attributed to a single cause. Surface deterioration is caused by turbulent flow created by deposit/solid particles, increased water droplet erosion, vibration during operation, rotor thrust, and material damage/erosion caused by impact/reflection in other areas due to surface roughness formed locally.

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DECLARATION OF ETHICAL STANDARDS
The authors of this article declare that the materials and methods they used in their studies do not require ethics committee approval and/or legal-specific permission.

AUTHORS' CONTRIBUTIONS
Murat Kayaalp: Conducted the experiments and analyzed the results.
Hasan Hasirci: Conducted the experiments, analyzed the results, and wrote the article.
Hakan Ates: Completed the writing of the article and edited it.

CONFLICT OF INTEREST
There is no conflict of interest in this study.

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