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Invited Review

Review of the fatigue behavior of hard coating–ductile substrate systems

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Abstract: With the wide application of coating materials in aerospace and other fields, their safety under fatigue conditions in service is important. However, research on the fatigue properties of ceramic hard coatings started late, and a unified standard is yet to be established to evaluate the fatigue life of hard coating–ductile substrate systems. Studies also present different opinions on whether coatings can improve or reduce the fatigue life of substrates. In this paper, the influence of the properties of ceramic coatings on fatigue performance is reviewed, and the effects of coating on the mechanism of fatigue crack initiation in substrates are discussed, aiming to help readers understand the fatigue behavior of hard coating–ductile substrate systems.

Keywords: fatigue; hard coating; residual stress; fracture toughness; film thickness

1. Introduction

With technological advancements in surface modification, surface coatings have gradually become widely used because of their high efficiency and economic advantages for improving the wear [1] and corrosion [2] resistance of substrate materials. With the application of ceramic hard coatings in aerospace [3], automotive, and other high-tech fields [4], the fatigue performance of coated materials has become quite important for ensuring their service safety.

In 1903 [5], when an iron specimen was subjected to repeated loading and unloading, a slip would appear on individual crystals and develop into cracks, leading to the final fracture. The previous study [5] was the earliest published idea that metal fatigue fracture occurs because of the accumulation of plastic deformation. After more than 100 years of development, a remarkable research progress on metal fatigue has been made [6−7], including the understanding of initiation mechanisms. Different metals have two crack initiation modes: cyclic irreversible slip [6] and stress concentration at interior defects [7].

Although studies on the deformation of coating–substrate systems were performed as early as 1958 [8], the first reports on the fatigue properties of these systems, along with the rapid development of hard coating technology, were published in the 1990s [9−11]. In the 2000s, studies have explored thermal spray coatings as a possible alternative to structural parts because of the high residual tensile stress in traditional chromium-plated coatings, which lead to a poor cracking resistance [12]. Further studies have gradually focused on the fatigue properties of hard coatings to explore the effects of the intrinsic properties of coatings on the fatigue life, residual stress [13−14], and mechanical properties [15] of a whole system. Many efforts have also been devoted to increasing the fatigue endurance of coated materials by improving coating deposition technology [16] and combining two surface treatment methods, such as sandblasting and thermal spraying [17]. Moreover, studies have investigated fatigue crack initiation and propagation mechanisms in coated materials.

The compact columnar structure of ceramic coatings delays fatigue crack initiation [18], whereas the structural inhomogeneity of thermal spray coatings leads to the early initiation of fatigue cracks [19]. Although the influence of coating material properties, such as toughness [20], residual stress [21], and structure [22], on fatigue performance has been comprehensively studied, a unified standard has yet to be established to evaluate the fatigue life of ceramic coating materials.

Interestingly, in modern reports, different opinions on whether a ceramic coating improves or reduces the fatigue life of a matrix have been presented. Studies have also shown that the effects of coatings on fatigue crack initiation vary be-

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cause of the different mechanisms of fatigue crack initiation in a metal matrix. In this paper, valuable results of studies conducted in the past 20 years are reviewed to discover the influence of coatings on the fatigue properties of matrices and enhance the understanding of the fatigue performance of ceramic coatings.

2. Coating properties dominating the fatigue behavior of substrates

2.1. Effects of residual stress

Residual stress is usually regarded as intrinsic stress in thin films [23]. It is induced by the difference in thermal expansion coefficients between coatings and substrates and structural inhomogeneity produced during coating deposition [24–26]. The residual compressive stress in ceramic coatings subjected to physical vapor deposition (PVD) can exceed 10 GPa [27], which leads to good tribological properties, suppressed crack growth, and improved corrosion resistance [28]. However, excessive residual compressive stress in coatings also causes their brittleness, resulting in delamination at the initial loading stage or even before loading [26]. Therefore, the appropriate residual compressive stress in coatings should be improved.

Suh *et al.* [29] deposited TiN and TiAlN on a 1Cr−1Mo−0.25V steel substrate and conducted rotary bending fatigue tests at room and high temperatures to verify the effects of coatings, and their results are shown in Fig. 1(a). They analyzed the stress distribution during loading, and the corresponding schematic is illustrated in Figs. 1(b), 1(c), and 1(d), where compressive stress and tensile stress are depicted as the stress below and above the dashed line, respectively. The distributions of high residual stress at room temperature and low residual stress at high temperatures are presented in Fig. 1(b). The actual stress on the surface of the coating and the substrate is much lower in Fig. 1(d) than that in the no-residual-stress state in Fig. 1(c), and this characteristic is beneficial to the fatigue life of the coated specimen. Fatigue tests reveal that the fatigue life of the substrate is improved by the coating at room temperature, and fatigue cracks initially form at the inclusions on the subsurface of the substrate because its tensile stress is higher than that in the interior.

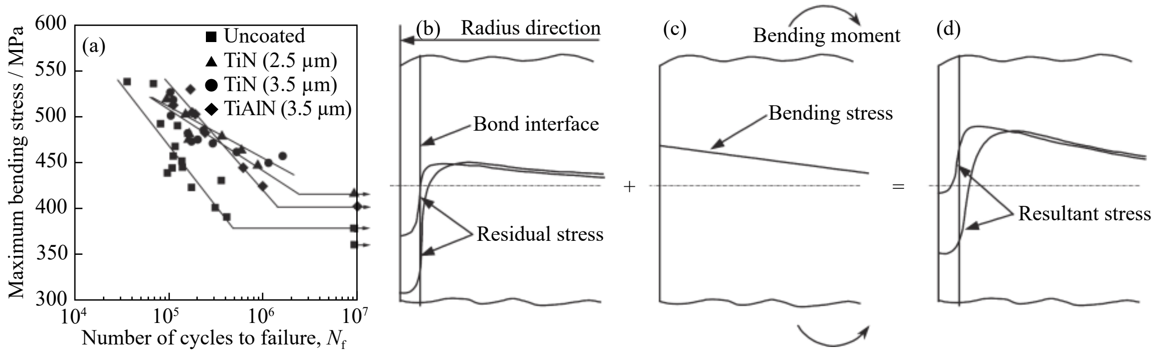

Fig. 1. Rotating bending fatigue test results of TiN- and TiAlN-coated 1Cr−1Mo−0.25V steel and schematic of stress distribution in the ceramic-coated specimen under the combination of residual and bending stresses: (a) fatigue results of the coated and uncoated material; schematic of (b) residual stress, (c) bending stress, and (d) combined stress. Reprinted from *Mater. Sci. Eng. A*, 343, C.M. Suh, B.W. Hwang, and R.I. Murakami, Behaviors of residual stress and high-temperature fatigue life in ceramic coatings produced by PVD, 1-7, Copyright 2003, with permission from Elsevier.

Saini and Gupta [30] examined the fracture morphology of WC/C-coated and uncoated steel samples subjected to four-point rotating bending fatigue. They found no significant difference, indicating that the mechanisms of fatigue crack initiation and propagation remain unchanged. The presence of coatings only affects the stress level for the occurrence of fatigue crack by inducing residual stress. Kovaci *et al.* [23] showed that hard coatings can delay fatigue crack growth by depositing a diamond-like carbon (DLC) film on AISI 4140 steel via PVD, increasing the surface hardness from a range of $HV_{0.01}$ 200–220 to a range of $HV_{0.01}$ 1400–1450, and inducing compressive residual stress up to 1.2–1.3 GPa. This observation is closely related to the high surface hardness and residual stress in the coating.

Yonekura *et al.* [31] investigated the effects of film thickness and residual stress on bending fatigue properties by preparing CrN coatings on Cr−Mo steel (Fig. 2). They observed that a high residual compressive stress is present in the coating, and the residual compressive stress increases first and then decreases with coating thickness. This result is consistent with previous findings [32]. In Figs. 1(a) and 2(a), film thickness slightly affects fatigue life. These results indicate that high residual stress is the main factor influencing the fatigue life of coated materials. Puchi-Cabrera *et al.* [33] also confirmed that the improved fatigue performance of a TiN-coated 316L substrate is mainly related to the residual compressive stress in coatings and the good adhesion between coatings and substrates.

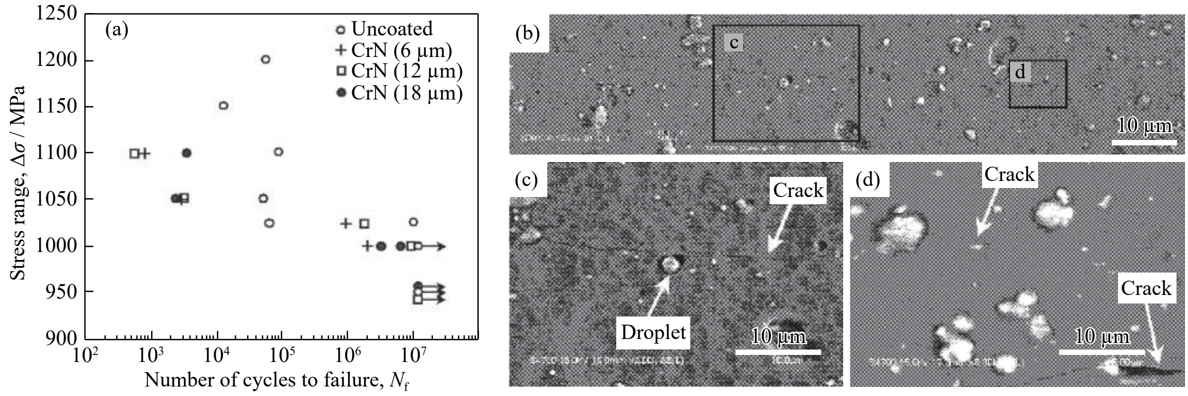

Fig. 2. Three-point bending fatigue tests of a CrN-coated Cr−Mo steel substrate: (a) fatigue of the coated and uncoated steel with different film thicknesses; (b) coating defects affecting the fatigue crack path under a film thickness of 18 μm, stress range (Δσ) of 1000 MPa, and number of cycles to failure (N_f) of 7.3 × 10^6; (c) and (d) are the magnified areas of (b). Republished with permission of World Scientific Publishing Co., Inc., from Fatigue properties of nitride Cr−Mo steel with CrN thin film deposited by AIP method, D. Yonekura, A. Tsukuda, R.I. Murakami, and K. Hanaguri, 17, 2003; permission conveyed through Copyright Clearance Center, Inc.

Residual compressive stress can be used to improve the fatigue strength of coated materials. Oskouei *et al.* [34] increased the compressive stress in TiN coatings via a post-heat treatment (PHT) from 4.54 to 7.56 GPa. They found that this increase is attributed to thermal stress formed during cooling and caused by the difference in the thermal expansion coefficients between coating and substrate materials. Although the residual compressive stress in the coating is high before heat treatment, the fatigue life of the substrate is shorter than that after heat treatment (Fig. 3). A further increase in the residual compressive stress via PHT compensates the reduction of the fatigue life of the coating.

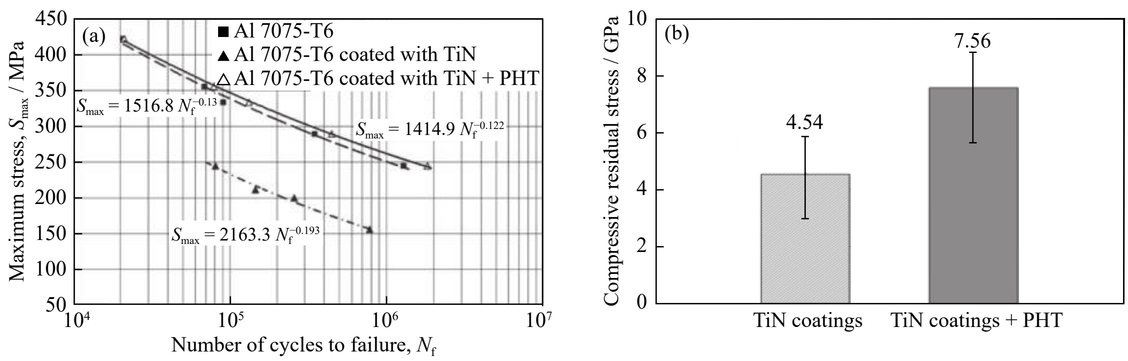

Fig. 3. Axial fatigue test and coating stress measurement results of the TiN coating on Al 7075-T6 alloy with and without PHT: (a) fatigue results with a stress ratio (*R*) of 0.1 and a frequency of 15 Hz and (b) compressive residual stress within as-deposited TiN coatings and TiN coatings after post heat treatment. Reprinted from *Thin Solid Films*, 526, R.H. Oskouei, R.N. Ibrahim, and M.R. Barati, An experimental study on the characteristics and delamination of TiN coatings deposited on Al 7075-T6 under fatigue cycling, 155-162, Copyright 2012, with permission from Elsevier.

2.2. Effects of coating defects and surface roughness

Defects on the surface of metals without coating trigger the initiation of fatigue cracks, resulting in premature cracking failure. Similarly, defects in coatings can initiate fatigue cracks. Costa *et al.* [35] deposited DLC, CrN, and TiN coatings via PVD on a Ti−6Al−4V alloy. They found that DLC, CrN, and TiN coatings have film thicknesses of 2.4, 4, and 4 μm, respectively, and their corresponding surface roughness values (R_a) are (0.57 ± 0.13), (1.08 ± 0.15), and (1.06 ± 0.04) μm. Axial fatigue test was performed to investigate the coating effect of the coatings, and the relationship between the loading cycles and maximum stress (σ_{max}) is showed in Fig. 4(a). As shown in Fig. 4(b), DLC has a compact structure with almost no defects in the coating; thus, the fatigue resistance of DLC-coated samples is higher than that of other samples. In Fig. 4(c), the defects in the CrN coating act as the initiation sites of fatigue cracks, which cause the prior cracks in the coating to extend toward the interior of the substrate. As such, the fatigue resistance of the CrN coating is lower than that of DLC. In Fig. 4(d), the TiN coating exhibits the lowest fatigue strength because of many microvoids.

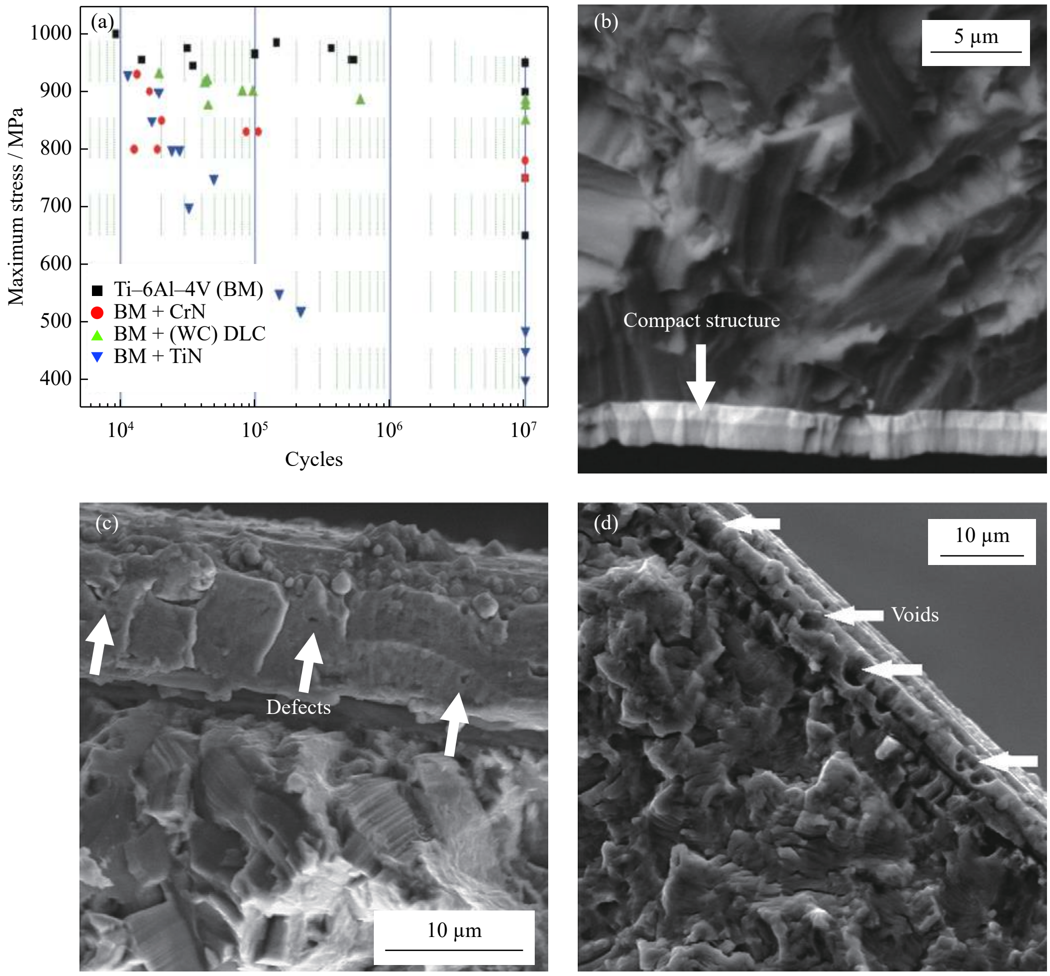

Fig. 4. Axial fatigue test results of PVD-coated Ti–6Al–4V with a frequency of 20 Hz and a stress ratio of 0.1 at room temperature: (a) fatigue results of the coated and uncoated materials, (b) fracture surface of the DLC-coated Ti–6Al–4V with σ_{max} = 900 MPa and N_f = 79932, (c) fracture surface of the CrN-coated Ti–6Al–4V with σ_{max} = 800 MPa and N_f = 18888, and (d) fracture surface of the TiN-coated Ti–6Al–4V with σ_{max} = 520 MPa and N_f = 217630. Reprinted from *Int. J. Fatigue*, 33, M.Y.P. Costa, M.L.R. Venditti, M.O.H. Cioffi, H.J.C. Voorwald, V.A. Guimarães, and R. Ruas, Fatigue behavior of PVD coated Ti–6Al–4V alloy, 759-765, Copyright 2011, with permission from Elsevier.

Yonekura *et al.* [31] confirmed that a CrN coating slightly decreases fatigue strength because of its defects (Fig. 2). Coating defects affect the crack propagation path because cracks in coatings more likely pass through these defects, as seen in Figs. 2(b), 2(c), and 2(d). Therefore, reducing the surface roughness and defects of coating materials is beneficial to their fatigue performance.

2.3. Effects of hardness

Nishida *et al.* [36] measured the Vickers microhardness of a DLC-coated Ti–6Al–4V alloy. The hardness of the coating increases with deposition time and gradually decreases with the distance from the surface. Rotating bending fatigue test results show that the fatigue strength of the coated specimen increases with hardness, and the cycle ratio of the initiated fatigue microcracks changes from 53% for the uncoated material to 84% for the coated material. Therefore, the high hardness of the coating delays the initiation of fatigue cracks in the coating. As a result, the fatigue life of the coated titanium alloy improves.

Ferreira *et al.* [37] deposited several PVD coatings on a 42CrMo4 steel, measured the microhardness and residual stress of coatings, and conducted three-point bending fatigue tests, as presented in Fig. 5(a). The residual stress in WTiN and WTi coatings is similar but is much higher than that in other coatings illustrated in Fig. 5(c). However, the fatigue resistance of the WTi-coated samples is higher than that of the WTiN-coated samples and the best among all the coated samples. In this case, the increase in the fatigue life of PVD-coated materials can be attributed to the high coating hardness, as described in Fig. 5(b).

2.4. Effects of coating structures

Coating structures significantly affect the fatigue cracking

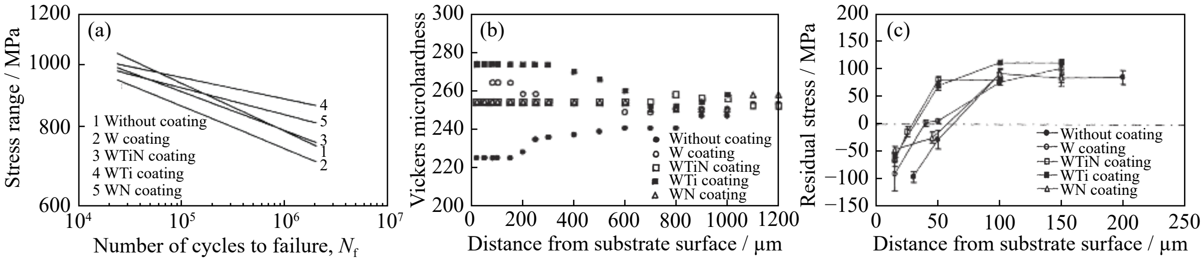

Fig. 5. Three-point bending fatigue test results for the PVD-coated 42CrMo4 steel and the microhardness and residual stress measured from the surface to the interior of the material: (a) fatigue results of the PVD-coated steel and the bare steel, (b) microhardness from the surface to the interior material, and (c) residual stress measured from the surface to the interior material. Reprinted from *Int. J. Fatigue*, 19, J.A.M. Ferreira, J.D.M. Costa, and V. Lapa, Fatigue behaviour of 42Cr Mo4 steel with PVD coatings, 293-299, Copyright 1997, with permission from Elsevier.

behavior of coated specimens because of the possibility of the nucleation of fatigue cracks in surface coatings and their propagation into bulk materials [38]. Yıldız *et al.* [20] deposited TiAlN coatings on a Ti−6Al−4V alloy via closed field unbalanced magnetron sputtering with biased-DC and pulsed-DC methods to produce an ordinary columnar coating structure and a compact, dense, and noncolumnar coating structure (Fig. 6). Their structure changes because of the higher energy of the atoms sputtered from targets and deposited more densely on the substrate via the pulsed-DC method than those via the biased-DC method [39]. The plain fatigue limits of the coated Ti alloy are increased by approximately 5% and 10% by the columnar and noncolumnar structures, respectively. Therefore, the compact columnar structure of ceramic coatings delays the initiation of fatigue cracks. This phenomenon is the main reason for the higher fatigue cracking resistance of pulsed-DC TiAlN coatings than that of biased-DC coatings.

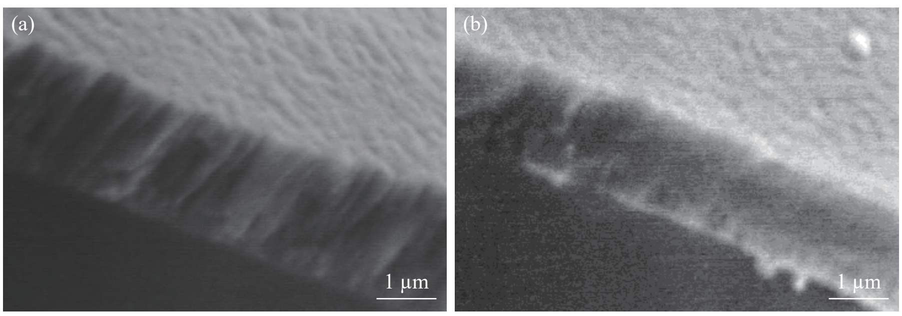

Fig. 6. Cross-sectional SEM images of TiAlN thin film: (a) biased-DC and (b) pulsed-DC. Reprinted from *Tribol. Int.*, 66, F. Yıldız, A.F. Yetim, A. Alsaran, A. Çelik, İ. Kaymaz, and İ. Efeoğlu, Plain and fretting fatigue behavior of Ti6Al4V alloy coated with TiAlN thin film, 307-314, Copyright 2013, with permission from Elsevier.

In another study, a multilayered structure is developed to improve the mechanical properties of coating materials [40]. Interfaces between different layers are efficient in preventing the movement of dislocations; thus, plastic deformation is prevented. The combined mechanisms of the shear deformation and plastic (twinning) deformation of multilayered structures allow coatings to tolerate a greater degree of plastic deformation than that of a monolayer structure without failure, including delamination and cracking; at the same time, hardness increases [41].

CrN/Cr multilayered coatings with multiple bilayers and the same total thickness are prepared on a Ti−6Al−4V surface through arc ion implantation to explore the effects of multilayered structures on fatigue properties [42]. Tension–tension axial fatigue tests with a frequency of 10 Hz and R of 0.05 are conducted. The microstructure of the coatings is shown in Figs. 7(a)–7(d), and the fatigue results indicate that the CrN single layer and two Cr/CrN bilayers have fatigue resistance similar to that of the uncoated Ti alloy, whereas three, four, and five Cr/CrN bilayers present a higher fatigue resistance than the other layers do. A ductile Cr layer can effectively prevent crack propagation, which initiates in a brittle CrN layer [41]. The high fatigue resistance of coatings with three–five bilayers is attributed to the combined effects of the layer interface preventing dislocation movement and the Cr layer hindering crack propagation.

2.5. Effects of toughness

The interface between a coating and a substrate can be subjected to high alternating shear stress upon loading by considering the remarkable difference in the elastic moduli of a brittle coating and a ductile substrate; however, this condi-

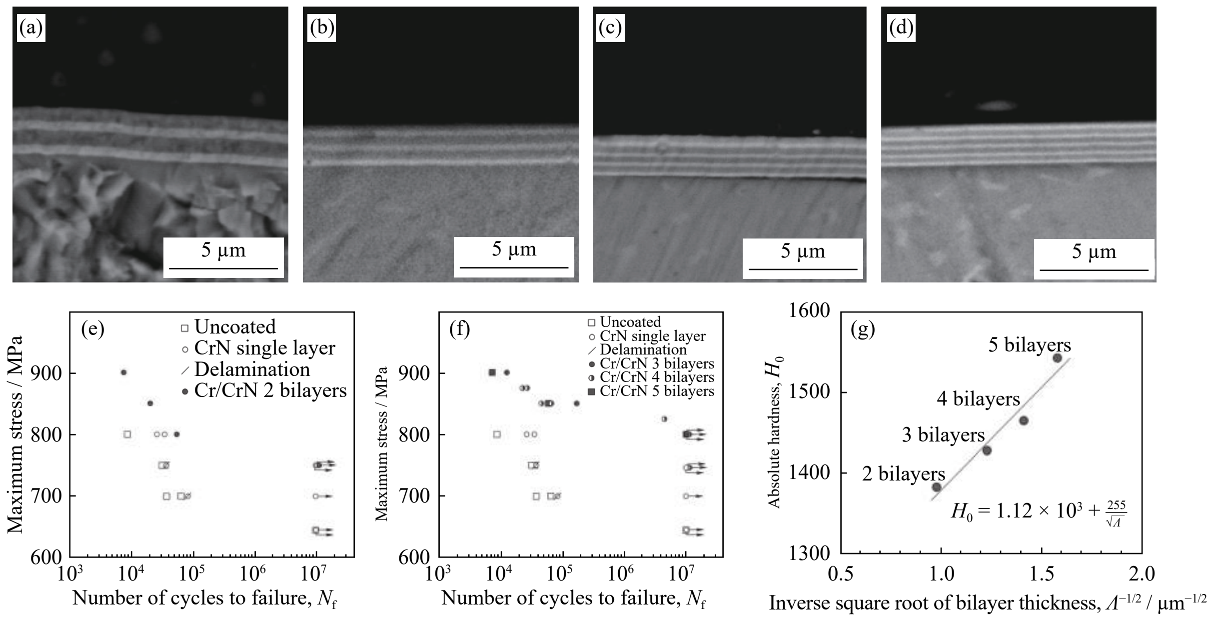

Fig. 7. Multilayered structural morphology and axial fatigue test results of the Cr/CrN coatings deposited via arc ion implantation with the same total thickness: structural morphology of the coatings with (a) 2, (b) 3, (c) 4, and (d) 5 bilayers; fatigue results of (e) the coating with 2 bilayers, (f) the coating with 3–5 bilayers, and uncoated Ti alloy; (g) surface hardness of the coatings. Reprinted from *Surf. Coat. Technol.*, 275, D. Yonekura, J. Fujita, and K. Miki, Fatigue and wear properties of Ti–6Al–4V alloy with Cr/CrN multilayer coating, 232-238, Copyright 2015, with permission from Elsevier.

tion can result in the cracking and peeling of coatings [43]. Multiple crack sites induced by the cracking of coatings cause the premature failure of TiN-coated alloys [44]. Costa *et al.* [45] illustrated that a brittle coating cracks in early stages because the film cannot withstand the large strain applied by the matrix.

These reasons can explain why the beneficial effects of a WC/C coating on an SAE8620 alloy fatigue can become harmful when the stress increases, as shown in Fig. 8 [30]. A high residual stress increases the fatigue limit of a coated alloy. However, when the stress increases, the strain in the matrix increases until the coating cannot bear it anymore, and poor elastic deformation leads to premature cracking and fatigue crack nucleation. Therefore, the fatigue life of coated alloys decreases.

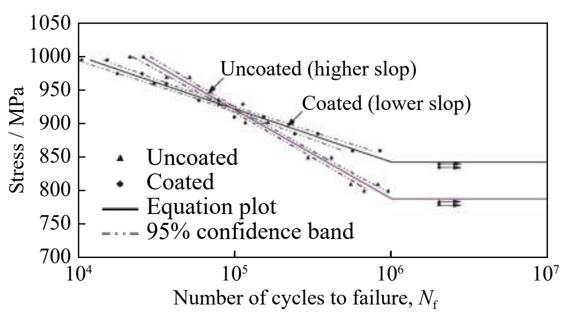

Fig. 8. Stress and number of cycles to failure relationship for uncoated and WC/C coated SAE8620 steel specimens. Reprinted from *Surf. Coat. Technol.*, 205, B.S. Saini and V.K. Gupta, Effect of WC/C PVD coating on fatigue behaviour of case carburized SAE8620 steel, 511-518, Copyright 2010, with permission from Elsevier.

A previous study discussed the effects of the plastic deformation resistance of coatings and the hardness-to-elastic modulus ratio (H^3/E^2) on fatigue endurance under good adhesion and structural uniformity [46]. Zhang *et al.* [47] deposited CrN and TiN coatings on a Ti−6Al−4V substrate and investigated the rotating bending fatigue properties with R of −1 and a frequency of 35 Hz. The indices of CrN and TiN are 0.405 and 0.169, respectively, and their fatigue limits decrease by 29% and 21%, respectively. The lower fatigue resistance of the CrN coating is related to the relatively poor plastic deformation. Their test results shown in Fig. 9 reveal that the prior cracking of the coating is attributed to the relatively low toughness.

2.6. Effects of coating thickness

Changes in coating thickness in a relatively small range (usually several micrometers) do not directly affect the fatigue life of a coated material; however, they indirectly influence fatigue performance by changing other coating properties, such as residual stress, hardness, and surface roughness. For example, thin AlN coatings possess a higher residual compressive stress and a smoother surface than thick coatings do [48]. The study of Suh *et al.* [29] and Yonekure *et al.* [31] indicate as coating thickness changes, the magnitude of residual stress and the hardness of coatings vary, and the change in the fatigue life of coating materials is the direct result of alterations in residual stress and coating hardness but

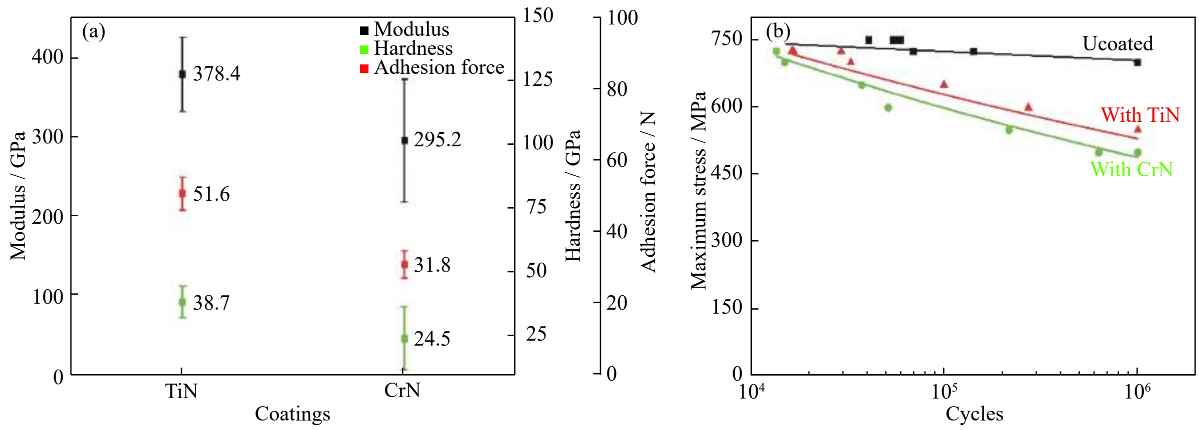

Fig. 9. Mechanical properties of TiN and CrN coatings deposited on a Ti−6Al−4V alloy with a thickness of 3 μm: (a) elastic modulus, hardness, and adhesion force of the coatings; (b) rotating bending fatigue test results of the coated and uncoated alloys [47].

not coating thickness. Pobedinskas *et al.* [48] and Akebono *et al.* [49] demonstrated that coating thickness affects surface roughness, and fatigue resistance changes accordingly.

3. Effects of coating on the mechanism of fatigue crack initiation

In previous studies [35,38,45], when a hard coating–ductile substrate specimen is subjected to cyclic loading, either bending or axial stress, a fatigue crack nucleates in a surface coating and propagates to the interior of a matrix because of the defects or intrinsic brittleness of coatings. However, the mechanism of crack propagation from coatings to substrates is not explained, that is, the effect of coatings on the mechanism of fatigue crack initiation is unclear. Thus, this section mainly discusses the effects of hard coatings on the fatigue cracking mechanism of alloys.

3.1. Coating cracking-induced fatigue crack initiation

The presence of hard coatings can inhibit the formation of sliding steps on the surface of metal substrates [50], and dislocation pileups form on the slip plane under the coating–substrate interface. Dislocation pileups lead to a high-stress concentration at the interface, resulting in the delamination and cracking of hard and brittle coatings. Then, coating cracks rapidly expand toward the interface and cause the cleavage cracking of the substrate [51]. The effect of hard brittle coatings on the initiation of fatigue cracks is demonstrated by the morphological characteristics of fatigue crack sources [52]. The uncoated Ti alloy shows typical subsurface nondefect fatigue crack origins [53], which are caused by an irreversible slip at the substrate subsurface [6]. However, the fractography analysis of the CrAlN-coated Ti alloy reveals a cleavage cracking area induced by coating cracks.

Once the coating begins to fail, several cracks appear in surface coatings under good adhesion. In Fig. 10, many fatigue crack sources are present on the fatigue fracture surface of a coated specimen. This observation also explains the phenomenon described in another study [44], which demonstrates that TiN coating promotes the initiation of multiple crack sites.

3.2. Effect of coatings on the mechanisms of fatigue crack initiation

In a study [54], the fatigue resistance of a TiN-coated Ti alloy is higher than that of a bare matrix under low stress; by contrast, the former is lower than that of the latter under high stress. In another study [55], although defects in coatings can stimulate the initiation of fatigue cracks, fracture analysis indicates that the fatigue cracks of a coated alloy initiate from inclusions and precipitations in the matrix. This finding shows that fatigue crack initiation is caused by the joint action of many factors, not by a single factor. The influence of hard coatings on the fatigue properties of a matrix is closely related to the types of fatigue crack sources of a substrate material; these sources can be divided into inclusion fatigue crack source in matrices [56] and nondefect fatigue crack source on substrate subsurfaces [57].

The crack initiation of a fatigue crack source without inclusions on the substrate subsurface is mainly due to the accumulation of dislocations and the formation of sliding steps on a material surface. After hard coatings were deposited, the existence of coatings inhibits the overflow of dislocations on the substrate surface and prevents the formation of sliding steps. Under coatings, the accumulation of dislocations forms a stress field and accelerates the cracking of coatings. The cracks in coatings rapidly propagate toward the surface of the matrix, causing the cleavage to crack at the substrate surface and initiating fatigue cracking. The improvement of the fatigue properties of a coated alloy depends on the anticracking ability of the coating itself. The residual compressive stress, compact structure, high hardness, and good ductility of coatings are beneficial to the fatigue resistance of a coated alloy. Therefore, the fatigue life of a substrate is shortened under high stress as a coating cracks more quickly under high stress because of its intrinsic brittleness.

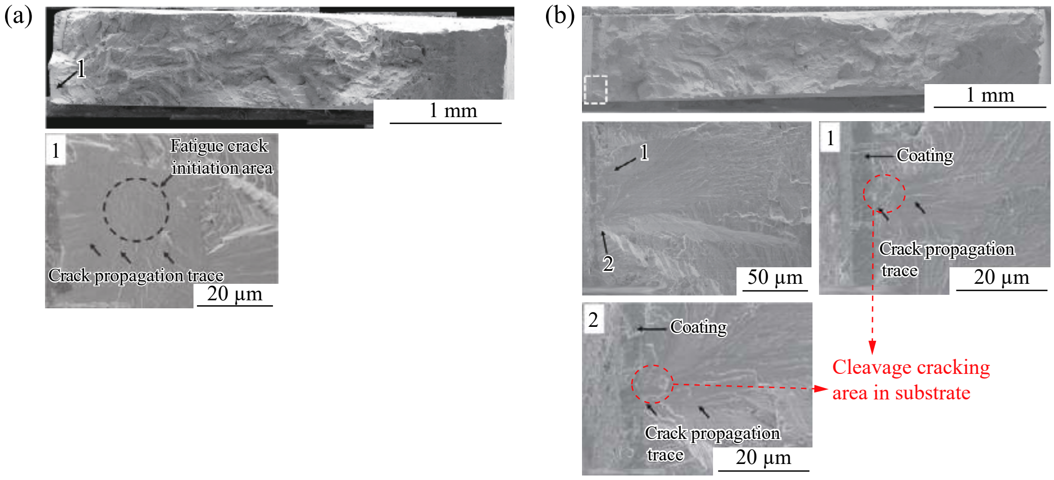

Fig. 10. Morphology of the fatigue crack source of the Ti−6Al−4V alloy without and with CrAlN coating with a thickness of 4.5 μm, axial tension–tension fatigue, *R* of 0.1, and frequency of 60 Hz: (a) uncoated Ti−6Al−4V failure under 515 MPa after 60888 cycles and (b) CrAlN-coated Ti−6Al−4V failure under 450 MPa after 56864 cycles. Reprinted from *Int. J. Fatigue*, 125, Y.Y. Bai, Y.T. Xi, K.W. Gao, H.S. Yang, X.L. Pang, X.S. Yang, and A.A Volinsky, Brittle coating effects on fatigue cracks behavior in Ti alloys, 432-439, Copyright 2019, with permission from Elsevier.

Fatigue cracking initiated at inclusions in a matrix is controlled by two mechanisms, namely, inclusion initiation and coating cracking-induced initiation. During fatigue test loading, a coating plays a positive role in delaying inclusion initiation because of the introduction of residual compressive stress, high surface hardness, and good surface integrity. However, when the life of the fatigue crack of a coating is shorter than that of the inclusion fatigue crack initiation of the matrix alloy, the mechanism of the fatigue crack initiation of a material changes, and the mechanism of fatigue crack initiation of the substrate as induced by hard coating cracking dominates fatigue failure. At this time, hard coating reduces the fatigue life of the matrix.

4. Future prospects

Fatigue failure in engineering is a process by which material damage accumulates under the action of multiple factors. Based on existing research results, the following suggestions are proposed to improve the fatigue performance of coating materials.

As for the cleavage cracking of a matrix material caused by the prior cracking of the coating in service, the length of cleavage cracks in the matrix is proportional to the propagation rate of a coating crack into a substrate. Therefore, reducing the propagation rate of cracks in coatings is an efficient way to prolong the fatigue life; for example, a multilayer structure [41] can be introduced by taking advantage of the blocking effect of coating interfaces.

The toughness of a coating should be enhanced to ensure the high hardness and a compact structure. Nanoscaled deformation twins [58] and structural transition [59] can be introduced to improve the toughness of coatings.

Ceramic coatings can effectively introduce a high residual compressive stress on the surface of a matrix, but a high residual stress may cause the premature cracking of coatings. Therefore, obtaining an appropriate residual compressive stress [60] in coatings have beneficial effects on fatigue resistance.

Reducing the surface roughness and defects in coatings is a key to minimizing the nucleation point of fatigue cracks and extending the fatigue life.

5. Conclusions

The development history and key factors of the effects of hard coatings on the fatigue performance of metal matrices are summarized, and the mechanisms of the fatigue crack initiation of coated metals are discussed. The compact structure, compressive residual stress, high hardness, and good surface integrity of coatings are attributed to the positive influence on the fatigue resistance of alloy substrates. However, poor intrinsic toughness can lead to the prior cracking of coatings under high stress. Subsequently, the coating crack-induced mechanism of fatigue crack initiation likely dominates the failure of coated alloys. As such, coatings should be prevented from prior cracking during fatigue service to improve the fatigue life of coated alloys. The initiation of fatigue cracks can be delayed by enhancing the toughness of coatings, maintaining appropriate residual compressive stress, and reducing coating defects.

Acknowledgements

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