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Experimental Investigation of Micro-Hardness & Tribological Behavior of Composite Coating for Wear Resistance Application

Ankit Tyagi[1], Peeyush Vats[2], Rekha Nair[3,*], Sangram keshari Das[4], Manish Bhandari[5], Amit Meena[5]

Abstract

The author effectively created a composite coating with enhanced durability utilizing the HVOF technique in this investigation. The automobile business has encountered fierce worldwide rivalry, rapid technical breakthroughs, and strict regulatory regulations in recent year.. Producers of lubricants, gasoline additives, and worldwide original equipment manufacturers (OEMs) are striving to address the difficulties presented by changing consumer preferences and emerging energy conservation and environmental protection regulations. We have successfully created and analyzed composite coatings by the HVOF method, with the goal of improving resistance to wear. The existence of composite coating on steel was verified by FESEM and EDS, demonstrates the presence of a composite coating, characterized by the aggregation of composite particles and an uneven surface structure, as well as the occurrence of porous imperfections and also demonstrating favourable mechanical characteristics such as micro-hardness, as well as outstanding tribological performance. This study has the potential to uncover new uses for composite coatings on steel substrates, namely in areas that require enhanced mechanical strength, resistance to corrosion, and increased performance in friction and wear. The present study was investigated using FESEM, micro-hardness and tribo-meter testing. These composite phases demonstrated excellent mechanical qualities, such as high micro-hardness, and exceptional tribological performance, including low coefficient of friction and high wear resistance. The composite coating was subjected to testing at various temperatures (60, 120, 180°C). The researchers noted that the micro-hardness of the composite coating increased as the temperature rose, which was attributed to the development of oxide and carbide layers within the composite coating. The wear testing findings revealed that the composite coating exhibits lowest COF (0.15), and 30 μm wear at 180°C temperature.

*__Author for Correspondence__
Rekha Nair

[1]Associate Professor, Department of Mechanical Engineering, Poornima College of Engineering, Jaipur, Rajasthan, India
[2]Professor, Department of Mechanical Engineering, Poornima College of Engineering, Jaipur, Rajasthan, India
[3] Professor, Department of Chemistry, Poornima College of Engineering, Jaipur, Rajasthan, India
[4]Assistant Professor, School of Electrical & Electronics Engineering, VIT Bhopal University, Bhopal, Madhya Pradesh, India
[5]Assistant Professor, Department of Mechanical Engineering, MBM University, Jodhpur, Rajasthan, India

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Keywords: Composite; composite coating; micro-hardness; wear resistance; wear test

INTRODUCTION

The automobile business has encountered fierce worldwide rivalry, rapid technical breakthroughs, and strict regulatory regulations in recent years [1]. Producers of lubricants, gasoline additives, and worldwide original equipment manufacturers (OEMs) are striving to address the difficulties presented by changing consumer preferences and emerging energy conservation and environmental protection regulations [2]. Enhancing engine friction, decreasing wear, and conserving natural resources are all essential benefits of fuel-efficient automobiles and energy-saving lubricants [3]. According to Skjoedt et al., a decrease of 10% in

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the amount of friction in engines of all U.S. passenger automobiles might have led to a save of 3.4 billion gallons of fuel in 2007 alone [4]. Studies have demonstrated that by minimising power loss, decreasing wear, and providing an efficient sliding contact in piston rings, the lifespan of the component can be greatly extended. Regrettably, the interaction between the piston-liner continues to be a significant cause of deterioration, especially when subjected to typical loads and engine speeds in internal combustion engines. Research conducted by Gawel et al. and Drozdz et al. showed that applying SiC and chromium to steel surfaces improves the steel's resistance to oxidation at high temperatures, as well as enhancing its mechanical and corrosion properties [5, 6]. Typically, coatings like chrome, NiCr, Al-Si alloy, MoO, and CrC with Mo powder are used on the piston-cylinder assembly to increase the lifespan of the component and minimise friction [7-15]. Nevertheless, these coatings commonly experience issues such as elevated internal tensions, inadequate oil compatibility, and restricted thermal stability. Consequently, there is a decrease in the utilisation of durable coatings in piston rings. At now, materials such as composite nanofibers, CNTs, and DLC are extensively utilised to improve the performance of friction and wear and may be readily purchased for use in modern engines [16]. Tyagi et al. have documented that applying DLC coatings to piston rings enhances their wear resistance and prolongs the lifespan of the piston-cylinder assembly [17]. Nevertheless, the utilization of DLC coatings in piston rings remains constrained by the slow rate of deposition and limitations associated with chemical composition. Hence, there is a requirement to create novel tribological coatings for piston rings in the contemporary automobile sector.

This project aims to produce and characterize composite coatings using the HVOF method for applications that require wear resistance. The objective is to estimate the tribological behavior and micro-hardness of the composite coating.

EXPERIMENTAL PROCEDURE

The steel substrates were initially prepared by grinding with emery paper ranging from 180 to 2000 grit. Subsequently, they were polished using grain size of 10±2μm. The steel substrate's surface roughness was determined to be 0.2±0.01μm, and its micro-hardness was measured to be 250±5HV. During the sliding test, the steel substrate demonstrated a coefficient of friction of 0.4, and Wear of 80μm. The HVOF thermal spray process was employed to deposit high-quality composite coatings onto the steel substrate, with a specific focus on enhancing wear resistance. The surface morphology of the composite coating was analyzed and characterized using a JEOL FESEM with EDS attachment.

The micro-hardness of the coated samples was assessed using Vickers micro hardness tester, having capacity of 1000mN, and indentation load of 300mN. The tribological test of the coated samples was assessed using tribometer, having 850^0C maximum temperature, and 100N load. The tribometer allowed for testing in a safe environment with no toxic or corrosive elements. For the evaluation of tribological qualities, a set of 4 circular discs and 4 cylindrical pins were used. The investigating parameters for the wear test undertaken in this research are presented in Table 1. The term "CC" in this study stands for composite coating. Specifically, CC1 represents at room temperature, CC2 represents 60°C, CC3 represents 120°C, and CC4 represents 180°C. The performance of the composite coating was evaluated in extreme conditions using dry lubrication, where the tribological system functions without any lubrication.

Table 1. Wear test parameter.

No.	Parameter	C 1	C 2	C 3	C 4
1	Temp. (°C)	Room	60	120	180
2.	Sliding velocity (m/s)	1	1	1	1
3.	Load (N)	60	60	60	60

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EXPERIMENTAL RESULTS

Coating Characterization

Figure 1 displays the FESEM and EDS images of both the samples without a coating and the samples with a coating. The FESEM in Figure 1(a) demonstrate that the uncoated material possesses a consistent structure but displays porosity and void imperfections. On the other hand, Figure 1(b-c) demonstrates the presence of a composite coating, characterized by the aggregation of composite particles and an uneven surface structure, as well as the occurrence of porous imperfections while Figure. 1 (d) shows the EDS analysis of composite coating [18, 19].

Micro-Hardness

Figure 2 illustrates the investigational results for micro-hardness of the composite coating. The composite coating's hardness was assessed at different temperatures (60, 120, 180°C), yielding values of 300.7, 322.5, and 345.5 HV, respectively. The hardness of the coating at 180°C was significantly greater than that of coating at room temperatures and at 60°C, and 120°C. The improvement in hardness is due to the improved bonding strength between the coated particles of micron size and the alterations in grain alignment at high temperatures. This is mainly attributed to the development of a tribolayer on the surface, which provides excellent anti-wear capabilities.

In summary, the findings of this study indicate enhanced mechanical characteristics of the composite coating, particularly in terms of its environmental advantages compared to other coatings. Based on the preceding explanation, it is evident that the composite coating demonstrates increased hardness as a result of the development of carbide layer and the strong connection between the micron-sized coated particles.

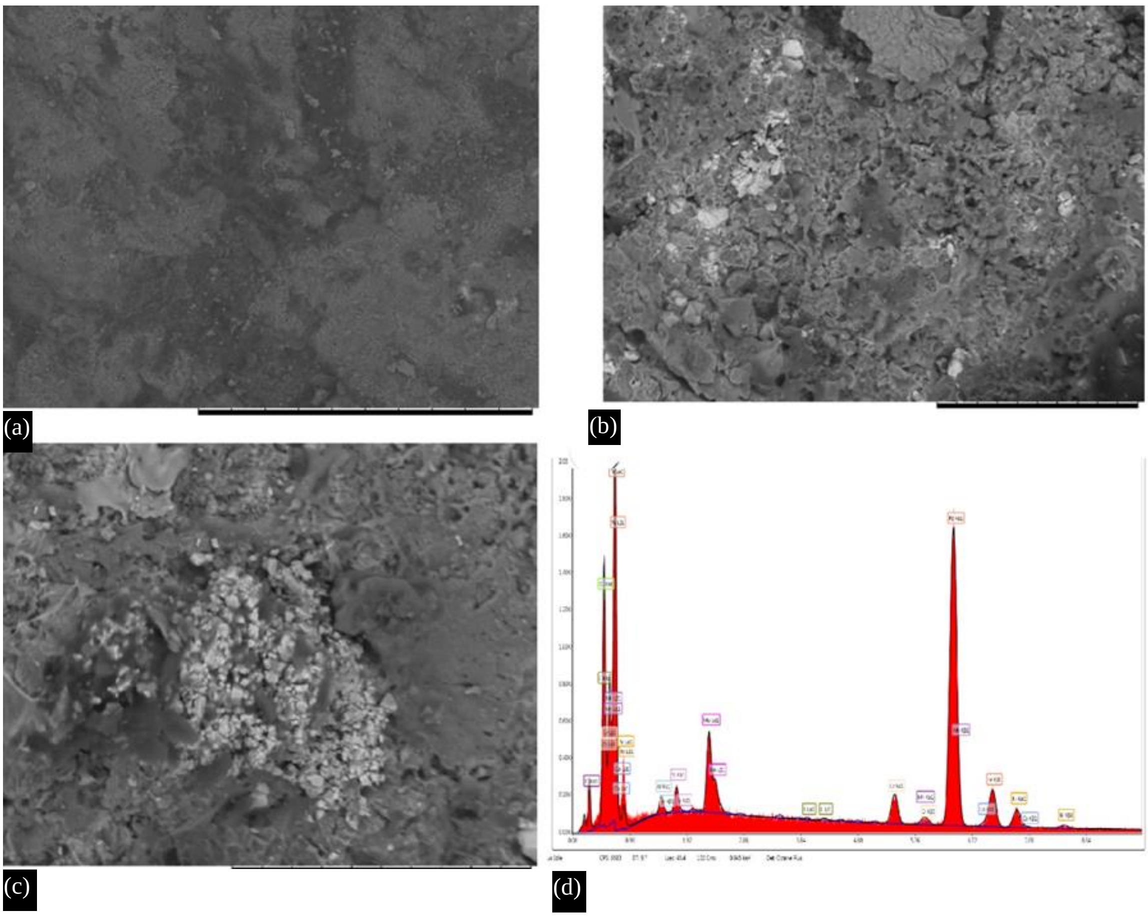

Figure 1. (a) FESEM image of uncoated sample (b-d) FESEM & EDS result of coated sample.

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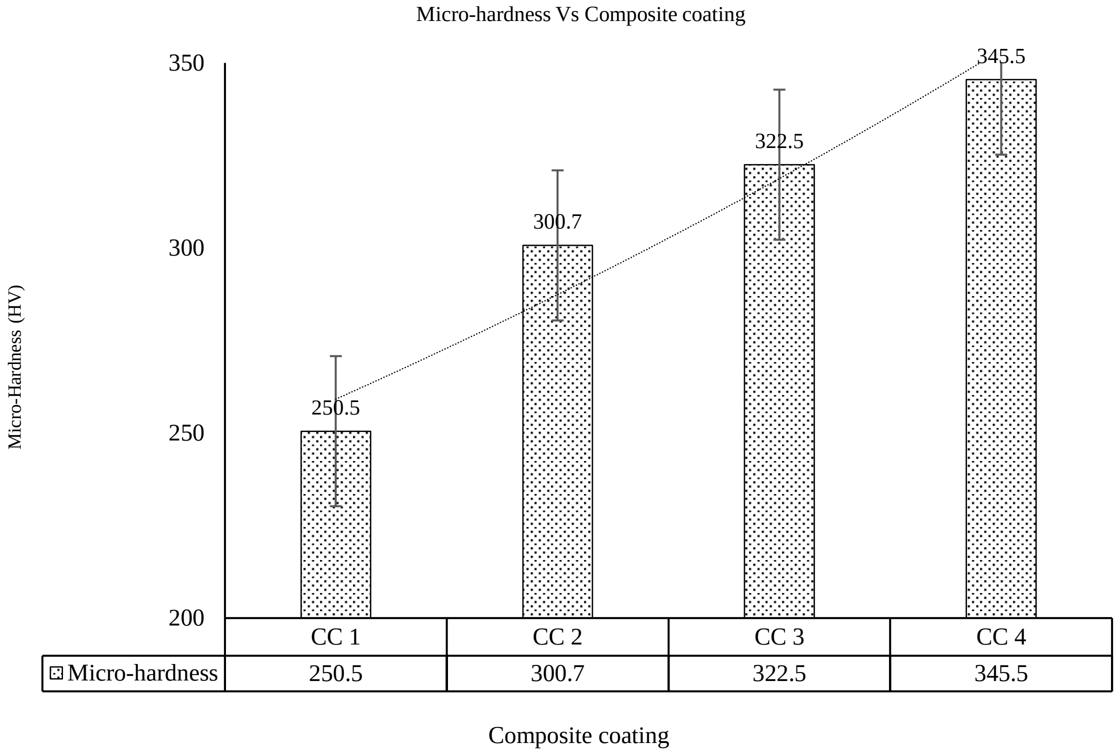

Figure 2. Micro-hardness result.

Tribological Behavior

The experimental study was carried out to investigate the wear and COF characteristics of composite coatings, with a specific focus on their performance in applications requiring resistance to wear. The evaluation of the created coating's performance relies heavily on the COF and wear, which are both crucial factors. Figure 3(a) depicts the changes in COF values for composite coatings that were tested at various temperatures. The counter body used in the tests was a cast iron cylinder liner. The mean coefficients of friction (COF) recorded 0.4 at room temperature, while 0.31 at 60°C, 0.25 at 120°C, and 0.15 at 180°C, for CC1, CC2, CC3, and CC4, respectively. As the temperature increased, the COF reduced from 0.4 to 0.15.

Figure 3(b) illustrates the relationship between wear and sliding distance for composite coatings test identical conditions. The mean wear recorded 80 μm at room temperature, while 66 μm at 60°C, 42 μm at 120°C, and 30 μm at 180°C, for CC1, CC2, CC3, and CC4, respectively. As the temperature increased, the wear reduced from 80 to 30 μm. The coatings had a significant amount of composite, which resulted in the creation of a solid lubricating layer. Additionally, the interaction between the coating and the counterpart caused graphitisation effects. The presence of this lubricating layer helps to decrease the COF and minimize wear. During the early phase of the running-in process, the COF, and wear experience an initial rise followed by stabilization [10-12].

The experimental findings suggest that the composite film on the steel substrate exhibits a correlation with temperature, with a decreased COF of 0.15 seen at a temperature of 180°C. The decrease in COF can be ascribed to the enhanced diffusion of composite, as seen in multiple studies [10-12]. or to the graphitisation phenomenon occurring at the contact region [16]. Furthermore, alterations in the alignment of grains and the existence of tiny composite particles with high hardness serve as obstacles to the process of plastic deformation and the wearing down caused by abrasion. As a result, this leads to a decrease in the COF, and wear [20]. This was mainly because a tribolayer with anti-wear capabilities formed on the coated surface.

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To summarise, this study shows that the composite coating has better tribological qualities than other coatings, especially in terms of environmental advantages. The discussion indicates that the composite coating effectively reduces the COF, and wear. This is attributed to the creation of a tribochemical film, improved composite diffusion, and the graphitisation effects that occur between the micron-sized composite coating and the counterbody during testing.

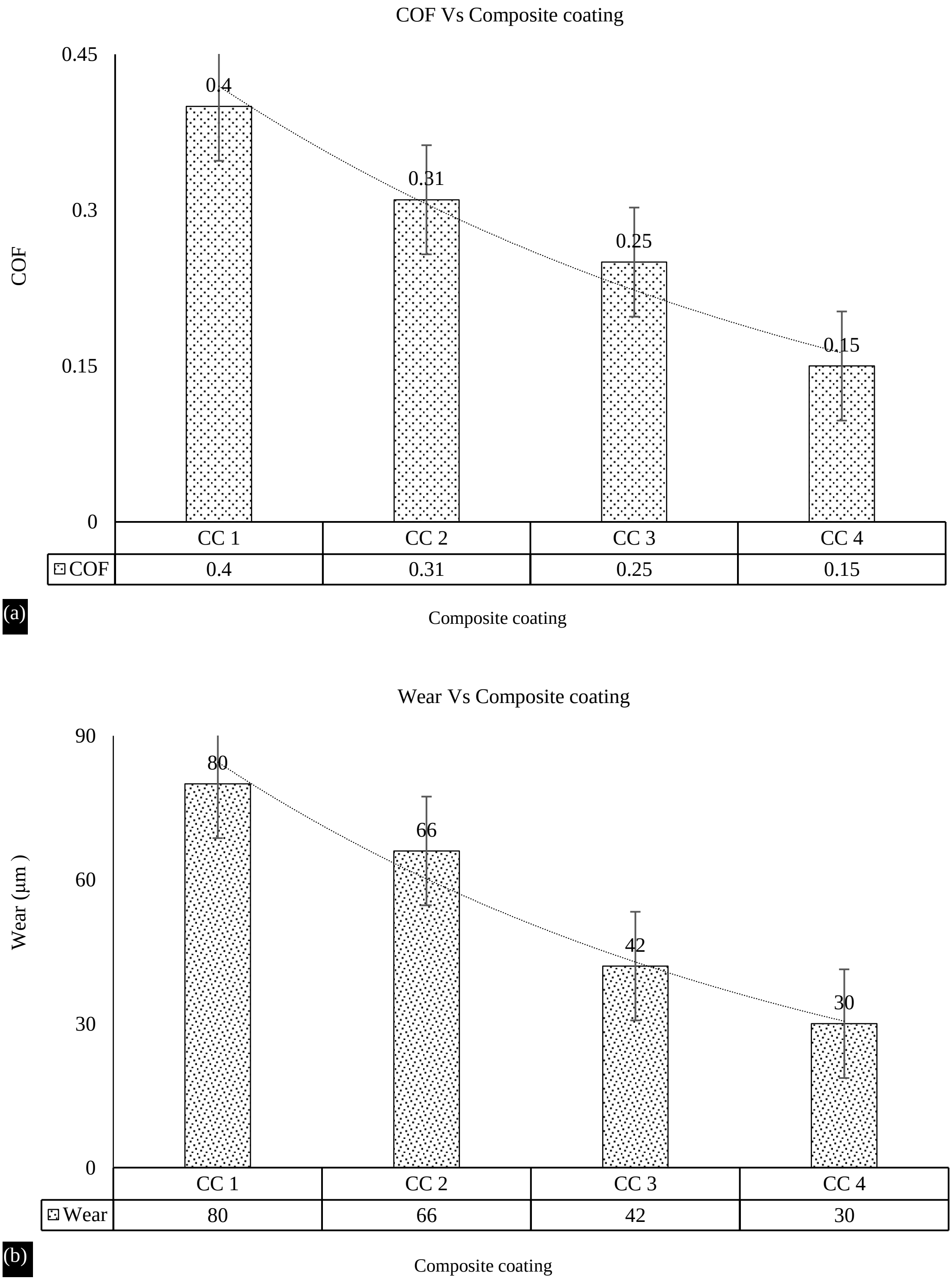

Figure 3. (a) COF (b) Wear result.

CONCLUSIONS

We have successfully created and analyzed composite coatings by the HVOF method, with the goal of improving resistance to wear. The existence of composite coating on steel was verified by FESEM and EDS, demonstrating favourable mechanical characteristics such as micro-hardness, as well as outstanding tribological performance. This study has the potential to uncover new uses for composite coatings on steel substrates, namely in areas that require enhanced mechanical strength, resistance to corrosion, and increased performance in friction and wear. The main conclusions of present study can be summarized as follows:

- The hardness of samples coated with composite was found to rise as the temperature rose, most likely because of the strong bond between the coated particles and the protective barrier created by composite particles of micron size, which prevent deformation under pressure.
- The composite coating demonstrated the most favorable results in terms of COF with a value of 0.15, and wear with a measurement of 30 microns. These results were obtained under a constant temperature of 180°C.

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