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CFD Simulation and Surface Modification of SG Cast Iron for Hot Rolling Applications

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Abstract

The wear resistance and heat dissipation of hot rolling mill rollers are critical factors affecting their durability and operational efficiency, particularly under extreme thermal and mechanical conditions. This study investigates the surface modification of SG iron rollers through tungsten laser cladding, aiming to improve these properties. A comprehensive approach, combining Computational Fluid Dynamics (CFD) simulations and experimental trials, was employed to evaluate the performance of tungsten-cladded rollers relative to untreated ones. The results revealed a 10-18% improvement in heat dissipation for tungsten-cladded rollers, attributed to enhanced heat transfer rates and better cooling efficiency. The analysis of fluid flow patterns, water volume fraction, and cooling angles demonstrated that tungsten cladding allowed for more effective heat management and uniform cooling across the roller surface. In the experimental trials, the mechanical properties of SG iron showed significant enhancement after laser cladding. The microhardness of the cladded surface increased by 59%, from 220 HV to 350 HV, offering improved resistance to surface deformation and wear. Furthermore, the wear resistance improved by 35% reduction in wear loss, as the tungsten and MoS_2/WC composite coatings provided a strong protective barrier against abrasion. Additionally, the Coefficient of Friction (COF) was reduced by 43%, from 0.7 to 0.4, due to the lubricating properties of MoS_2, minimizing frictional heat and energy loss during operation. These findings reveal the effectiveness of tungsten laser cladding as a surface modification technique for SG iron rollers, with practical implications for improving the durability and operational efficiency of hot rolling mill rollers.

Keywords: *Computational Fluid Dynamics (CFD), Heat Dissipation, Laser Cladding, Surface Modification, Wear Resistance*

Abbreviations:

CFD: Computational Fluid Dynamics.

FEM: Finite Element Method.

COF: Coefficient of Friction.

SG Cast Iron: Spheroidal Grey Cast Iron.

1.0 Introduction

Hot rolling mills are widely employed in the metal forming industry to produce a wide range of products, including high-strength alloys and building steel bars. However, the quick wear and deterioration of the rollers are significant issues with hot rolling mills because of the intense mechanical loads, high temperatures, and constant sliding contact with the hot work material. The rollers' lifespan is shortened and operating expenses rise due to high wear, surface deformation, and thermal fatigue caused by these conditions. It is crucial to have rollers that are strong, resistant to wear, and able to retain their mechanical and thermal characteristics in dynamic conditions. The techniques for surface modification, including laser cladding, can effectively

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countermeasure these issues to enhance productivity and reduce energy loss. Laser cladding techniques are used in surface modification in various engineering applications where wear substantially contributes to energy loss. Various surface modification techniques are used for the deposition of hard coatings to impart wear resistance, thermal strength, and corrosion resistance to enhance the service life of mechanical components. The scope of laser metal deposition is developing in surface modification techniques since various metal alloys can be cladded with enormous types of substrates in emerging applications.

The bionic approach in the present research study correlates the functional utility and the physics of engineered surfaces based on the ability of soil-borrowing animals like dung beetles to leverage those bionic geometrical patterns on their head surfaces to improve mobility velocity and reduce frictional forces. The authors explored the principle of nature-inspired design in surface engineering of rolling mills of rollers used for metal forming high-temperature steel billets. In this paper, the authors implement a novel bionic approach for selecting geometrical patterns to engineer the surfaces of mechanical implements. Oleksandr Kapustynskyi *et al.*[1] mention that wear, friction, and thermal stresses are the primary concerns in metal forming with hot rolling mills, as they influence output and energy efficiency. During rolling, wear and friction lead to premature tool failure and increased energy consumption. Weib *et al.*[2] conclude that surface modification techniques like laser cladding offer solutions by improving surface properties, reducing energy loss, and extending tool life.

John *et al.*[3] observed that high temperatures cause thermal stresses that aggravate these issues compromising material integrity. Xu *et al.*[4] highlight that integrating laser cladding with ultrasonic burnishing significantly enhances surface integrity and reduces wear, effectively addressing thermal and frictional challenges. Schirdewahn *et al.*[5] demonstrate that laser implantation of niobium and titanium-based particles can improve the tribological performance of hot working tool surfaces, further supporting the role of surface modification techniques in enhancing tool durability. These methods reduce energy loss during operations and extend tool life, contributing to more efficient and sustainable hot-rolling processes. Ocelík V. *et al.*[6] used a 2-kW continuous laser to fabricate Co-based coatings on compacted graphite and grey cast iron substrates. The authors established an empirical relationship between laser power, powder feeding rate, scanning speed, and the geometric features of its single track.

The authors found that the cracks propagated due to internal stresses from the bonding interface and layer interior where the thicker coating was deposited on a stiff substrate.

Milan J. *et al.*[7] aimed to discover the mathematical, experimental modelling used to define the rolling force and input parameters of the rolling process: absolute deformation, relative degree of deformation, coefficient and yield stress of materials. Analytical loading calculation of roller pair with approximation that concentrated forces replace the continuous roller loading to reduce the complexity of the process and experimental work to verify it. Based on experiment and regression analysis, a mathematical model was formed. Results obtained from mathematical modelling and experimental analysis were compared, and an excellent correlation was found.

L. Nalini *et al.*[8] studied two different materials, SG Iron and alloy cast steel, and concluded that SG iron for rolls is comparably better than alloy cast steel. The roller force could be reduced by reducing friction, using small diameter rolls, taking minor reductions per pass, rolling at elevated temperatures to reduce material strength, and using appropriate materials to manufacture the rolls.

Filippo *et al.*[9] proposed a finite element model of a hot rolling mill based on experimental tests regarding the mechanical characteristics of the material. The study presents a numerical simulation of the plastic deformation process in the hot rolling of AISI 304 stainless steel, focusing on the influence of temperature distribution. The stress-strain curve was evaluated through torsion tests, establishing the equivalence between the erosion and rolling process parameters using FEM commercial software. The torque and rolling force were compared with experimental measurements, validating the accuracy of the FE model. Sushant R.[10] revealed that the rolling force and strip temperature could be predicted by the FEM method with high accuracy. The paper describes a methodology for applying the output of the FEM software (DEFORM) to simulate the complete rolling mill in HSMM software, demonstrating the potential for reducing alloy consumption in steel.

Ganesh D. S. *et al.*[11] aimed to study the technological processes in rolling, examining factors influencing the fatigue life of rolls, such as rolling speed and time. Their analysis seeks to enhance fatigue life and reduce energy consumption, production costs, and product dimensional accuracy. The research focused on finite element analysis of hot rolling process parameters and high-temperature variables responsible for wear, leading to the selection of new wear-resistant roll grades. Lenard[12] studied the effect of process parameters on the coefficient of friction during cold, flat rolling of metals. The authors noted that independent variables and the mechanical attributes of the roller metal influence the coefficient. The experiments showed that friction increases with the reduction in strip metal and is affected by rolling speed, lubricant application, and the chemical composition of lubricants. Lenard and Barbulovic-Nad[13] established the relationship between the friction coefficient and significant process parameters during the hot rolling of low-carbon steel strips. Their tests measured roll separating force and roll torques as temperature, rolling speed, and reduction functions, determining the coefficient of friction through inverse calculations.

Zhan and Yang[14] focused on the effects of laser dimple texturing on the wear rate, highlighting its potential for engineering applications in surface texturing techniques. Charoo and Wani[15] explored the tribological properties of h-BN nanoparticles as lubricant additives, enhancing performance in cylinder liners and piston rings. Verma *et al.*[16] examined high-temperature wear in CoCrFeNiCux high entropy alloys, revealing the role of copper in wear performance. Sun *et al.*[17] enhanced the wear resistance of cast steel rolls through laser surface alloying, significantly improving durability. Sun *et al.*[18] also investigated laser surface alloying with C-B-W-Cr powders on nodular cast iron rolls, demonstrating its effectiveness in enhancing wear resistance. Szakaly and Lenard[19] focused on the impact of process and material parameters on the coefficient of friction in flat-die tests. Torims[20] discussed the application of laser cladding for mechanical component repair, emphasizing its regenerative capabilities. Evans and Bryan[21] reviewed structured, textured and engineered surfaces, offering an overview of their benefits. Blatter *et al.*[22] investigated lubricated friction in laser micro-patterned sapphire flats. Wang *et al.*[23] presented a loads-carrying capacity map for SiC thrust bearing design. Chang *et al.*[24] investigated microstructured milling tools for reducing wear. Deshmukh *et al.*[25] presented a method for developing bionic micro-textured nanocomposite patterns on mechanical implements. Deshmukh and Gogte[26] explored a biomimetic approach to surface modification, improving mechanical properties.

Due to exceptional mechanical qualities, Spheroidal Graphite (SG) cast iron is frequently used in hot rolling; however, high temperatures can cause wear and oxidation, impairing its performance. The wear resistance of SG cast iron has been investigated using surface modification techniques like laser cladding with hard coatings like W+MoS_2 coatings. However, issues like residual tensions, adhesion strength, and mismatches in thermal expansion still exist. Computational Fluid Dynamics (CFD) simulations have been used to analyze heat transfer and material flow during rolling to get insight into rolling parameter optimization. The studies have demonstrated that the CFD can precisely predict temperature distribution and rolling force. However, its particular applicability to SG cast iron substrates with hard coatings has yet to be explored.

The Tungsten (W) and its composites, such as W+MoS_2 and W+WC are known for their excellent hardness, wear resistance, and thermal conductivity, making them ideal candidates for surface protection in high-temperature applications. Applying these coatings can significantly improve the roller's ability to resist surface degradation and efficiently dissipate heat, extending its operational life. This study focuses on the application of tungsten laser cladding to SG iron rollers, a material commonly used in hot rolling mills. It evaluates the improvements in mechanical and thermal performance through a combination of Computational Fluid Dynamics (CFD) simulations and experimental trials. A few recent studies have shown that hard coatings can significantly enhance the wear resistance of industrial components. Still, limited literature explicitly addresses the application of tungsten laser cladding to hot rolling mill rollers. This study investigates the impact of tungsten cladding on SG iron rollers, focusing on quantitative improvements in heat dissipation and wear resistance.

The research aims to modify the surface of SG Cast Iron rollers with hard coatings like tungsten and evaluate the heat flux, temperature distribution, and wear rate

through CFD simulation and mechanical testing. By integrating CFD simulations and experimental trials, the study quantifies the heat transfer rate and reduction in temperature gradient resulting from surface engineering with creep-resistant coatings, such as Tungsten powder ($W+MoS_2$) or WC-10 Co-4 Cr. The laser surface modification approach offers insights into improving the wear resistance and thermal performance of mechanical components under operational conditions.

2.0 Materials and Methods

2.1 Materials

This study illustrates CFD Simulation of SG Cast Iron substrate with Tungsten (W) deposition using laser cladding in a Hot rolling mill. The experimental verification was carried out using Laser Cladding on SG Cast Iron 500/7 specimens to improve the Micro-hardness and Wear resistance. The mechanical properties

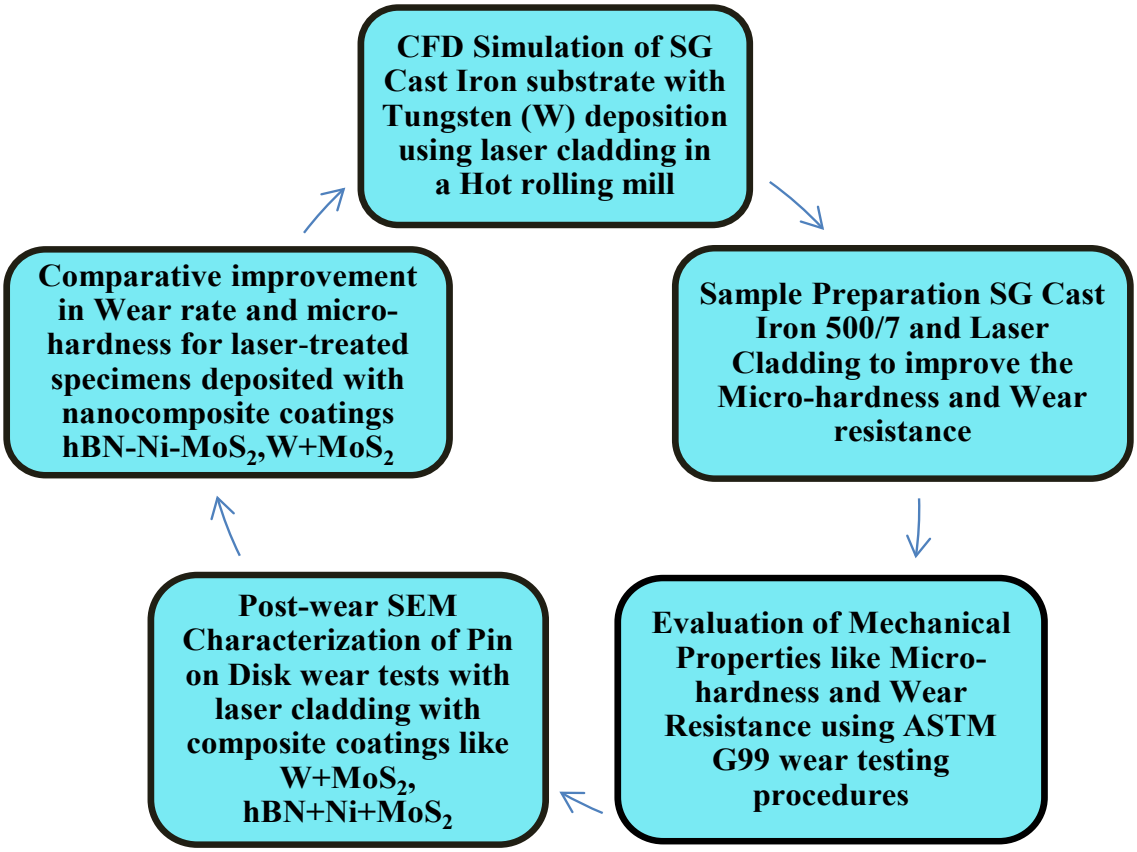


Figure 1. Flowchart depicting the procedure and analysis of tungsten laser-cladded versus untreated SG iron rollers using CFD simulation and experimental Investigations.

Table 1. Composition of materials used

Element	Carbon (C)	Silicon (Si)	Manganese (Mn)	Phosphorus (P)	Sulfur (S)	Magnesium (Mg)	Chromium (Cr)	Nickel (Ni)	Copper (Cu)	Iron (Fe)
SG 500/7 Cast Iron	3.60 - 3.80	2.20 - 2.60	0.10 - 0.30	≤ 0.035	≤ 0.015	0.03 - 0.07	-	-	-	Balance
Work Materials (Steel)	0.15 - 0.35	0.10 - 0.50	0.30 - 1.50	≤ 0.035	≤ 0.035	-	0.20 - 1.00	0.20 - 0.60	0.20 - 0.50	Balance

like micro-hardness and wear resistance were evaluated using ASTM G99 wear testing procedures. Post-wear SEM Characterization was carried out for the pin-on-disk wear tests specimens laser cladded with composite coatings like W+MoS_2, hBN+Ni+MoS_2. The composition of materials used is given in Table 1.

Figure 1 presents an integrated approach in research via CFD Simulation and experimental investigation of mechanical properties. The flowchart, including CFD simulation and experimental investigations, details the comprehensive procedure for evaluating the performance differences between tungsten laser cladding and untreated SG iron rollers.

The figure outlines essential steps, beginning with surface preparation and the application of tungsten coatings, followed by Computational Fluid Dynamics (CFD) simulations to analyze thermal performance. Subsequently, experimental trials were carried out to assess mechanical properties such as wear resistance and microhardness. This structured approach facilitates a detailed comparison of both roller types, emphasizing the benefits of laser cladding in improving roller performance in operational settings.

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2.2 Laser Cladding Experimental Setup

The substrate specimens were made from SG Cast Iron 500/07, closely matching the chemical composition of the SG iron rollers obtained from industry. Each specimen had a diameter of 10 mm and a length of 30 mm. The base metal underwent mechanical polishing using progressively finer grades of silicon carbide-impregnated emery paper, followed by polishing on a double disc polisher to achieve a mirror finish. After polishing, as depicted in Figure 2, the samples were treated using a fibre laser for laser surface texturing. In some cases, tungsten (W) powder was replaced on the surface for laser cladding, involving preplacement and subsequent laser remelting with the fibre laser. The tungsten powder had a particle size ranging from 1 to 6 μm, verified through Scanning Electron Microscopy (SEM) and Energy Dispersive X-ray Spectroscopy (EDX) analysis using a SIGMA HV instrument. The microstructural characteristics of the laser surface texturing and cladding were examined using SEM, EDX, and X-ray Diffraction (XRD).

2.3 Hardness and Wear Measurements

The mechanical properties were evaluated comparatively through microhardness testing, surface measurements, and pin-on-disc wear tests following ASTM standards. Hardness measurements were conducted on the laser-cladded and untreated SG iron samples. The microhardness tests were carried out on Future-Tech Microhardness tester with model no. FM-300 to measure

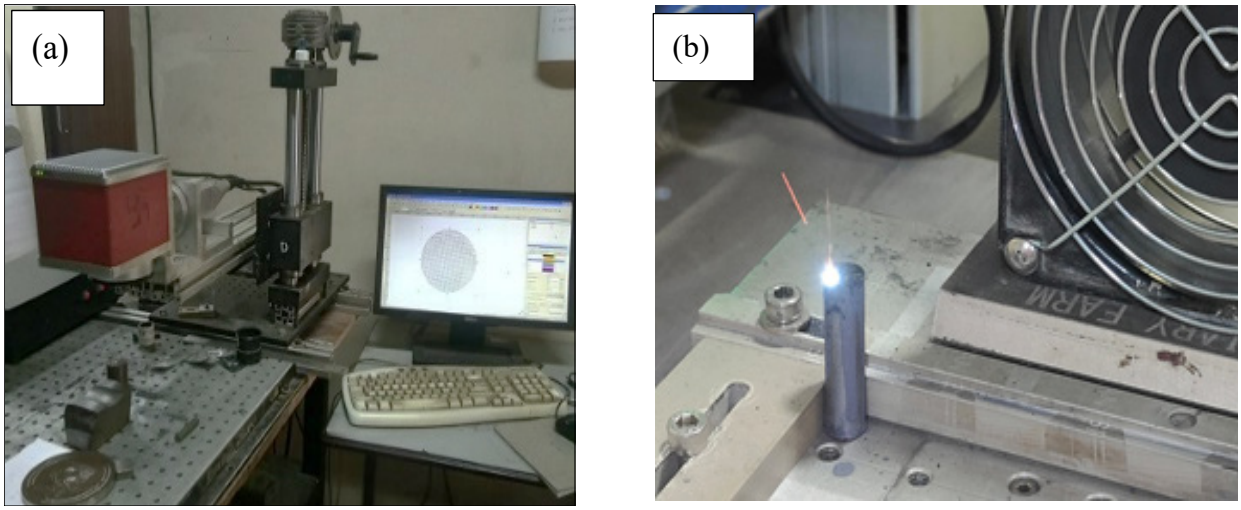


Figure 2. **(a)** Laser Cladding Setup23 **(b)** Laser Cladding of Tungsten on SG Cast Iron specimen.

Vickers' (HV) microhardness of thin film coatings, laser cladding on an SG 500/7 cast iron substrate.

The wear analysis was conducted using the Ducom Pin on Disk tribometer, as per ASTM G99 wear testing procedures. The experiments were performed under controlled conditions, employing a load of 2 Kg, a rotational speed of 200 rpm, and a sliding distance of 130 mm. Each wear trial lasted for 20 minutes.

2.4 Scanning Electron Microscopy

The FESEM characterization used the Carl Zeiss sigma model with EDS attachment by OXFORD instruments. Elemental distribution and surface morphology of the laser-cladded and untreated SG iron samples were investigated using Scanning Electron Microscopy (SEM) equipped with energy-dispersive X-ray Spectroscopy (EDS) for elemental analysis. SEM imaging was performed to capture high-resolution microstructural details, while EDS was employed to analyze the elemental composition across the surface. The samples were prepared by polishing and sputter-coating with a thin conductive layer to enhance imaging quality. The SEM-EDS characterization was conducted following standard protocols, and the data was evaluated using the imaging and analysis software provided with the SEM system.

3.0 Results and Discussion

The results and discussion section provides a comprehensive analysis of the experimental findings from both the Computational Fluid Dynamics (CFD) simulations and the experimental trials conducted on laser-cladded and untreated SG iron rollers. The experiments focused on evaluating key parameters such as heat dissipation, wear resistance, and microhardness to compare the performance of the two roller types. The discussion begins with the thermal performance of the rollers, as indicated by the CFD analysis, followed by the mechanical properties evaluated through microhardness tests and wear analysis. The section aims to correlate the experimental data with the observed performance improvements in laser-cladding samples, highlighting the impact of tungsten coatings on enhancing the thermal and mechanical behaviour of SG iron under operational conditions.

3.1 Computational Fluid Dynamics (CFD) Analysis

The preprocessing phase involved setting up the CFD model to define the necessary physical parameters, boundary conditions, and meshing to ensure accurate simulations. The CAD geometry of the roller stand and cooling nozzles was developed using SolidWorks, which accurately replicated the real-world hot rolling mill setup, allowing for precise simulation of thermal interactions and fluid flow, as depicted in Figure 3. The material properties of tungsten and SG iron were incorporated into the model to simulate heat transfer, as presented in Table 2. Tungsten was used as the cladding material, with a density of 19,300 kg/m^3, a specific heat capacity of 134 J/

Table 2. Material properties definitions for CFD Simulation [preprocessor parameters]

Inputs	Material	
parameter	**Tungsten**	**SG-Iron**
Density (kg/m^3)	19300	7000
specific heat capacity, Cp (J/gm K)	0.134	--
specific heat capacity, Cp (J/kg K)	134	506
thermal conductivity K (W/mK)	164	36.2
Thickness, t (mm)	0.4	0
roughness constant, M	6.2	3.2

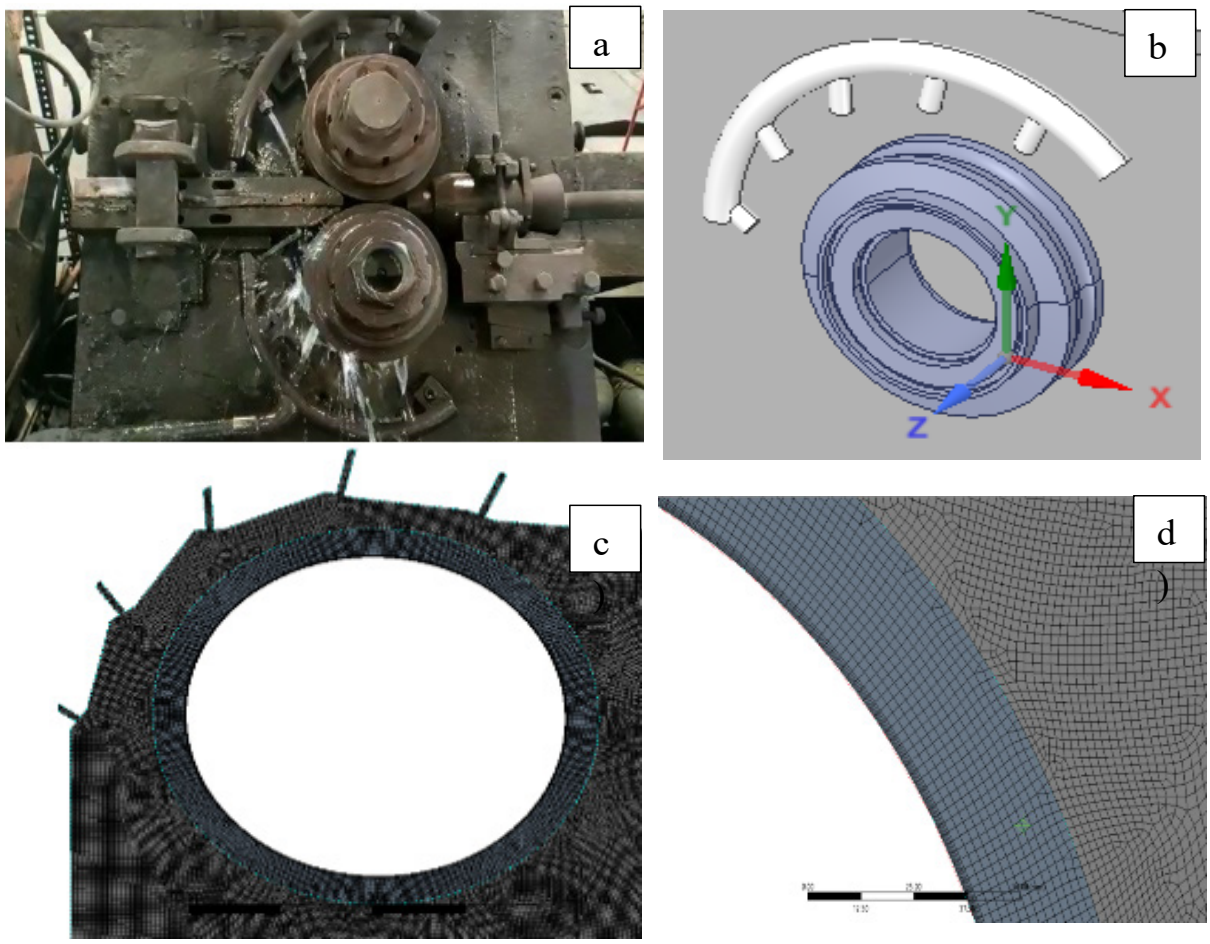


Figure 3. **(a)** Rolling mill with Cooling Nozzles **(b)** CAD Model **(c)** CFD Model, **(d)** Section of CFD Model.

kg.K, and a thermal conductivity of 164 W/m.K. SG Cast iron had a density of 7,000 kg/m^3, a specific heat capacity of 506 J/kg.K, and a thermal conductivity of 36.2 W/m.K.

A finely structured mesh was used to capture the detailed flow patterns of the water coolant and temperature gradients across the roller, focusing on the areas near the roller surface where heat transfer and fluid interaction were most intense.

In the processing phase, a transient analysis was conducted to simulate the time-dependent interactions between the rotating roller and the cooling water. The simulation lasted for 0.34 seconds, equivalent to one complete roller rotation, using a time step of 0.00005 seconds.

This provided a detailed view of the heat transfer and fluid flow processes, as illustrated in Figures 4a and 4b. It is also noted that from the CFD simulation, the fluid flow pattern around the untreated and tungsten-cladded SG iron rollers was thoroughly analyzed to evaluate the cooling efficiency and heat dissipation during operation. Water was modelled as a cooling fluid, with flow patterns significantly influenced by the surface characteristics of the rolling roller.

The water flow exhibited irregular behaviour for untreated rollers, resulting in a less uniform cooling effect. The water volume fraction was lower, especially near the roller surface, indicating insufficient cooling contact, which resulted in less effective heat dissipation.

The fluid contact angle was smaller, leading to poor water adherence to the roller surface and reducing the overall cooling rate. In contrast, the tungsten-cladded rollers demonstrated a more streamlined fluid flow

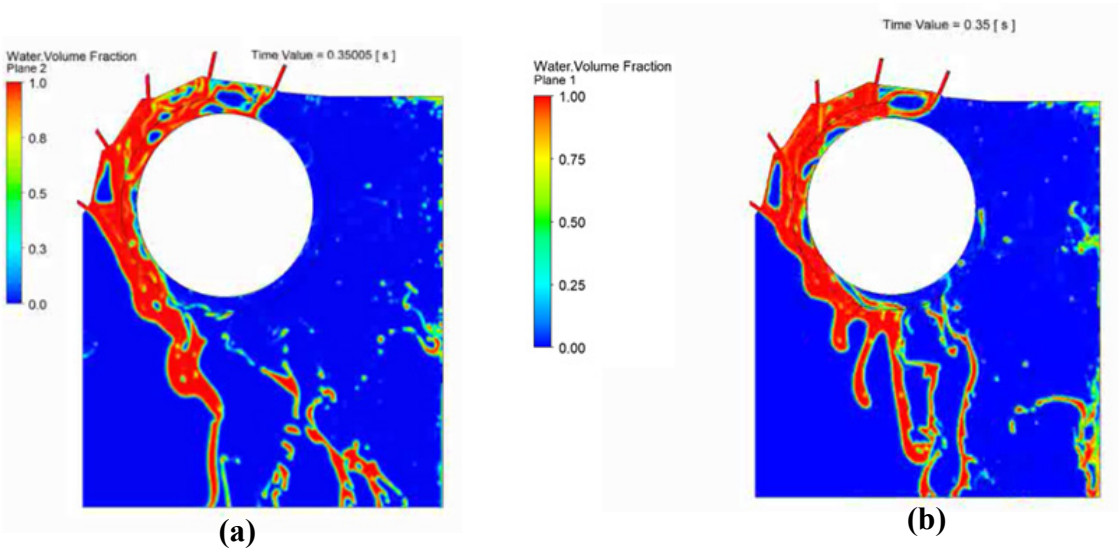


Figure 4. CFD Study of **(a)** SG Cast iron untreated substrate **(b)** Tungsten coated Cast Iron roller as a material of hot rolling mill rolls.

pattern, with a higher water volume fraction in the boundary layer, suggesting better water coverage and cooling efficiency. The cladding also increased the fluid contact angle, allowing for more consistent and intimate contact between the water and roller surface, improving cooling. The cooling rate for the cladded rollers was significantly higher due to enhanced heat transfer. The simulation revealed that the tungsten cladding helped maintain a lower and more uniform surface temperature, enhancing the heat transfer efficiency by 10-18% compared to untreated rollers. This consistent cooling pattern helps reduce thermal stresses and improves the roller's operational performance under high temperatures.

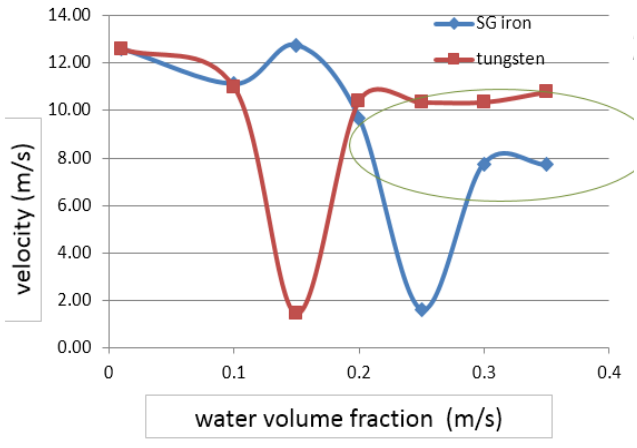


Figure 5. Velocity vs Water volume fraction.

In Figure 5, the roller operating at 174 RPM experienced significant heat flux due to contact with the 1173 K steel workpiece. The water-cooling system played a crucial role in dissipating this heat. To maximize heat removal efficiency, the velocity and pressure of the water were adjusted to maintain a steady flow across the roller surface. During the processing phase, calculations were made for velocity vectors, temperature gradients, and heat flux across the roller surface.

The interaction between water volume fractions and the rotating roller was also closely analyzed to determine how effectively the cooling system performed in both untreated and tungsten-cladded rollers. The heat transfer rate and cooling pattern observed in the CFD simulation were strongly correlated with the water velocity and the water volume fraction around the roller surfaces. In the case of untreated rollers, the lower water volume fraction and uneven cooling pattern led to less effective heat transfer. This was caused by inconsistent contact between the water and the roller surface due to higher surface irregularities and a larger fluid contact angle. Consequently, the cooling rate was reduced, resulting in inefficient heat dissipation. Additionally, lower water velocity in some regions further diminished the cooling

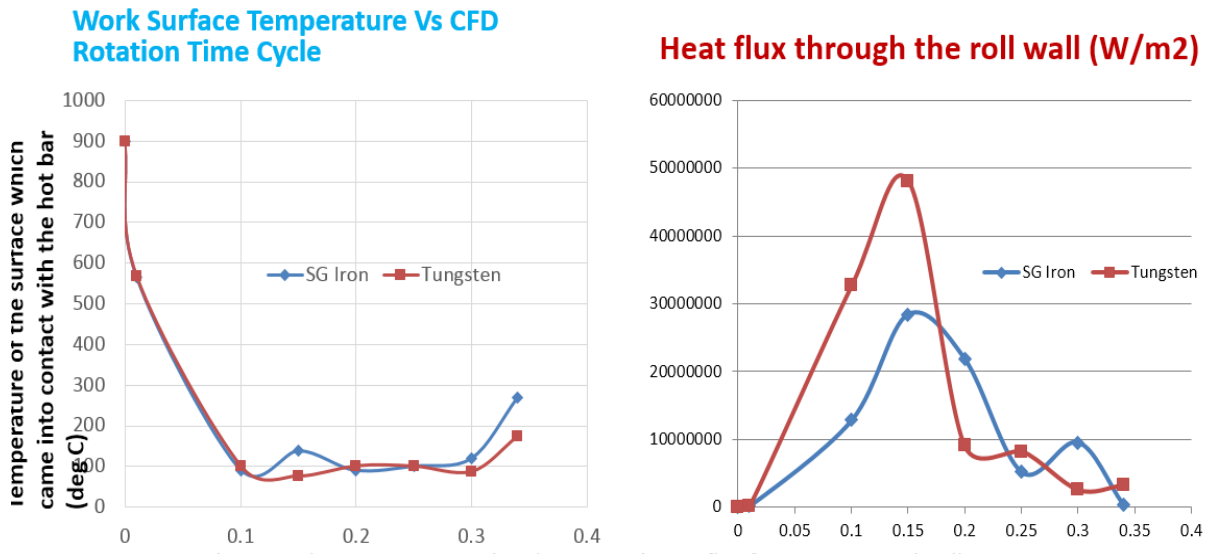


Figure 6. **(a)** Temperature distribution in tungsten-cladded rollers during hot rolling **(b)** Heat flux carried through roll wall for SG Cast Iron and tungsten coated roll surface in CFD time cycle of 0.35 seconds.

effect, leading to hot spots and thermal inefficiencies. In contrast, the tungsten-cladded rollers exhibited a higher water volume fraction and a more uniform cooling pattern. The smoother surface of the cladded rollers allowed for better water adherence, with a reduced fluid contact angle, ensuring consistent cooling. Thus, there is a correlation between heat transfer rate and cooling pattern in the context of the velocity of water and water volume fraction. As the contact angle of water increases, the cooling is higher, leading to enhanced heat transfer for CFD simulation of the Tungsten laser cladded roller.

In these cases, the higher velocity of water enhanced convective heat transfer, allowing quicker and more efficient heat removal from the roller surface. This resulted in a 10-18 % improvement in heat transfer compared to untreated rollers, providing a more stable temperature distribution and preventing localized overheating.

The simulation phase involved using ANSYS Fluent to model the cooling behaviour of untreated and tungsten-cladded SG iron rollers under high-temperature conditions. The Finite Volume Method (FVM) was employed to discretize the governing equations, with the Navier-Stokes equations used to simulate fluid flow and the heat conduction equation applied to calculate the temperature distribution across the roller material.

Turbulence in the cooling water flow was modelled using the k-ε turbulence model, which efficiently balanced accuracy and computational cost. Key outputs from the simulation included temperature profiles, velocity vectors, and heat flux distributions, allowing for an in-depth analysis of how tungsten cladding enhanced heat dissipation and maintained thermal stability during rolling operations.

As shown in Figure 6(a), the temperature variation across the roller surface and sub-surface regions revealed significant differences between the two types of rollers. The tungsten-cladded rollers exhibited a more uniform and lower surface temperature due to their higher thermal conductivity. In contrast, the untreated rollers showed uneven temperature distribution and the formation of hot spots. The heat transfer rate for tungsten-cladded rollers demonstrated a 10-18 % improvement in heat dissipation, further confirmed by the water volume fraction data, visualized in Figure 6(b) using ANSYS Fluent's post-processing tools. The cladded rollers maintained smoother cooling and reduced thermal stresses, with a more stable surface temperature, enhancing overall cooling performance. This improvement was achieved due to the tungsten cladding's ability to reduce the fluid contact angle, increase water adherence, and improve convective heat transfer rates.

The results in Figure 6(b), supported by ANSYS Fluent's advanced heat flux modelling, highlight the enhanced heat flux in tungsten-cladded rollers. The

combination of higher water velocity and volume fraction, visualized through ANSYS Fluent's streamline plots, allowed faster and more efficient heat removal, preventing thermal fatigue and localized overheating. In contrast, the untreated rollers experienced inconsistent cooling patterns and higher temperature gradients, leading to inefficient heat dissipation.

After comparing the performance parameters in CFD simulation, the velocity drop, as seen in Figure 5, was also seen as an increase in heat carried for the tungsten cladded roller, as shown in Figure 6(b). Thus, a correlation between temperature distribution and heat flux demonstrated that tungsten laser cladding improves cooling efficiency and enhances thermal stability, extending the operational life of the rollers. The ANSYS simulation results confirm that tungsten-cladded rollers offer superior performance in maintaining stability during high-temperature rolling operations, leading to longer service life and improved productivity.

3.2 Improvement in Microhardness, Wear Resistance, and Coefficient of Friction Improvement in SG Iron

In this study, significant improvements in the mechanical properties of SG iron were achieved through laser cladding with single material surface deposition like tungsten (W) and composite coatings such as W+MoS_2 and W+WC+MoS_2. These improvements were evaluated by measuring microhardness, wear resistance, and coefficient of friction, which are critical parameters for enhancing the durability and performance of SG iron components, especially in high-wear applications like hot rolling mills.

3.2.1 Microhardness

This increase in hardness can be attributed to surface modification using a uniform coating layer, which significantly enhances the surface's resistance to deformation and micro-cracking under load. The improved hardness directly correlates with better wear resistance, ensuring longer operational lifetimes for SG iron components used in high-stress environments, as shown in Figure 8.

3.2.2 Wear Resistance

The wear resistance was evaluated through comparative wear testing of untreated and laser-cladded SG cast iron samples. As depicted in Figure 8, untreated SG iron showed significant wear, characterized by deep grooves and material loss. In contrast, laser cladding with tungsten and composite coatings substantially reduced wear. The Coefficient of Friction (COF) was the critical

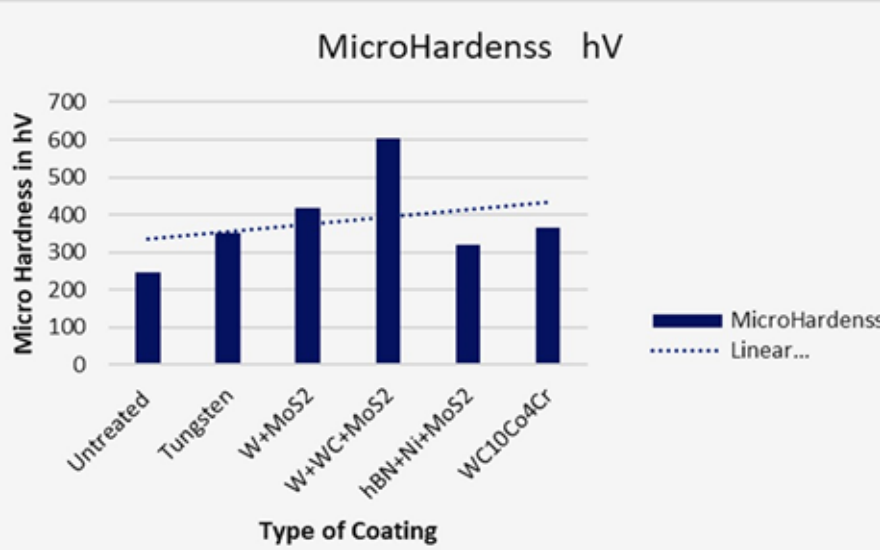


Figure 7. Improvement in microhardness of laser cladded with alternative single and nanocomposite coatings[27].

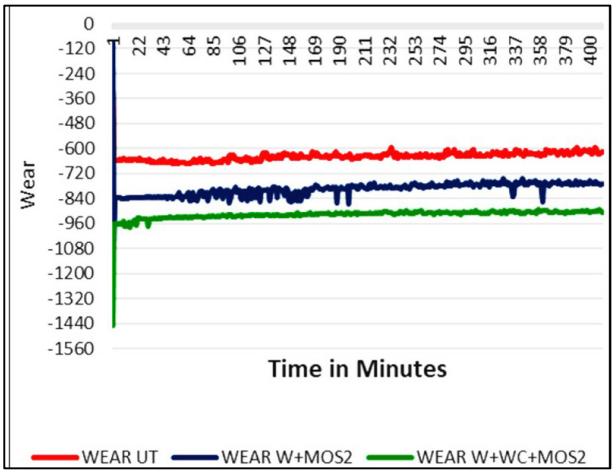


Figure 8. Enhancement in wear resistance of SG iron substrates of laser cladded with alternative single and nanocomposite coatings[27].

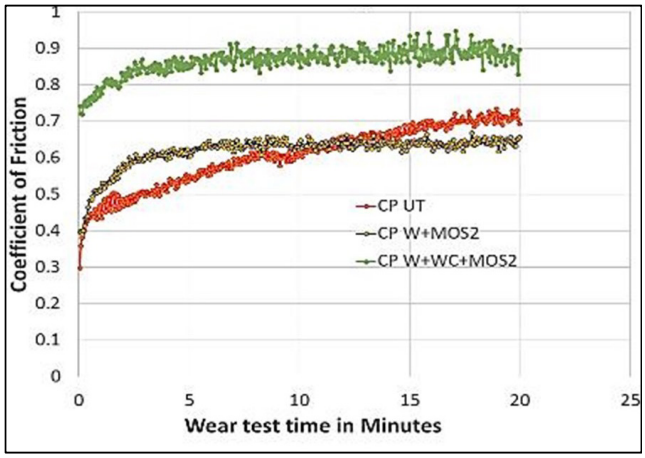


Figure 9. Enhancement in coefficient of friction in SG cast iron substrates via laser cladding with W+MoS_2 and W+WC+MoS2 coatings[27].

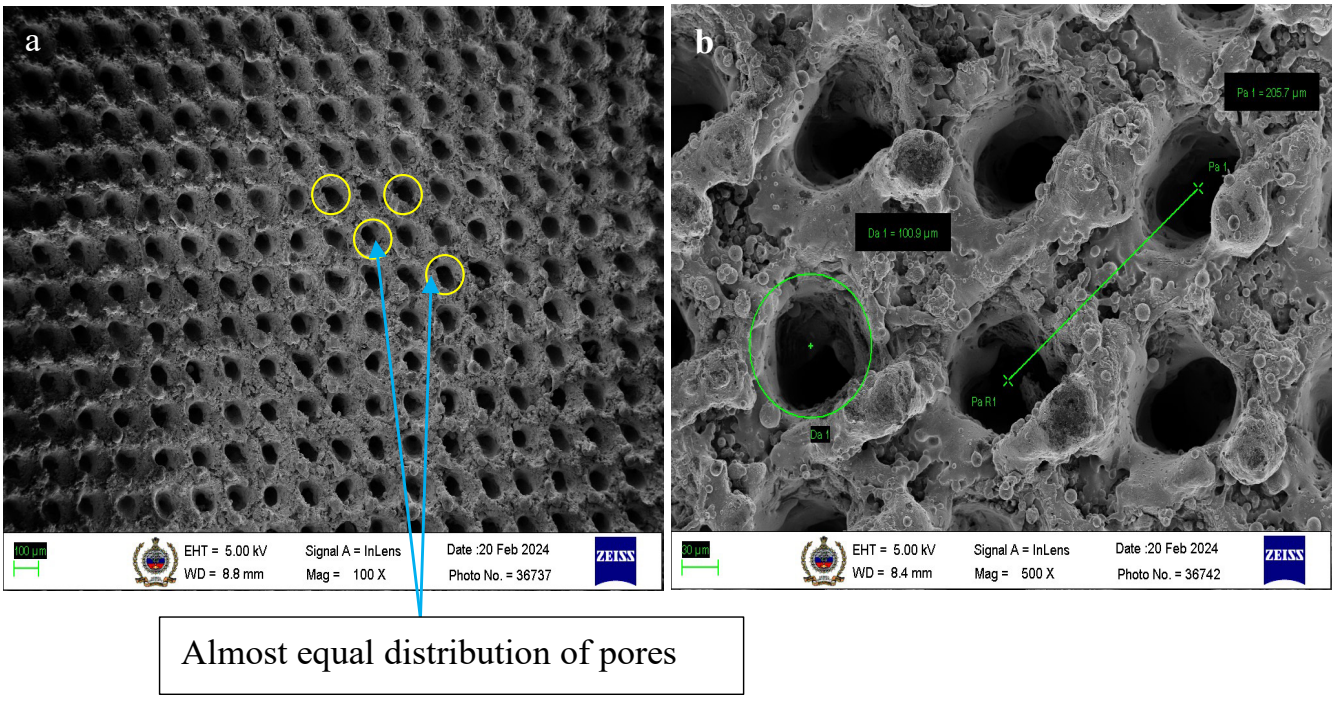


Figure 10. **(a)** W+MoS_2 laser cladded SEM images of SG cast iron specimen before wear, **(b)** WC-10Co-4Cr laser cladded SEM images of SG cast iron substrates before wear.

parameter affecting wear behaviour and energy efficiency. Untreated SG iron had a COF of 0.7, as shown in Figure 9. However, after laser cladding with W+MoS_2 and W+WC+MoS_2 coatings, the *COF* dropped significantly to 0.4, representing a 43% reduction. MoS_2, known for its solid lubricating properties, reduced friction between the contacting surfaces, enhancing operational efficiency.

Figure 10(a) shows that the laser-cladding surface appears uniform with evenly distributed porosity,

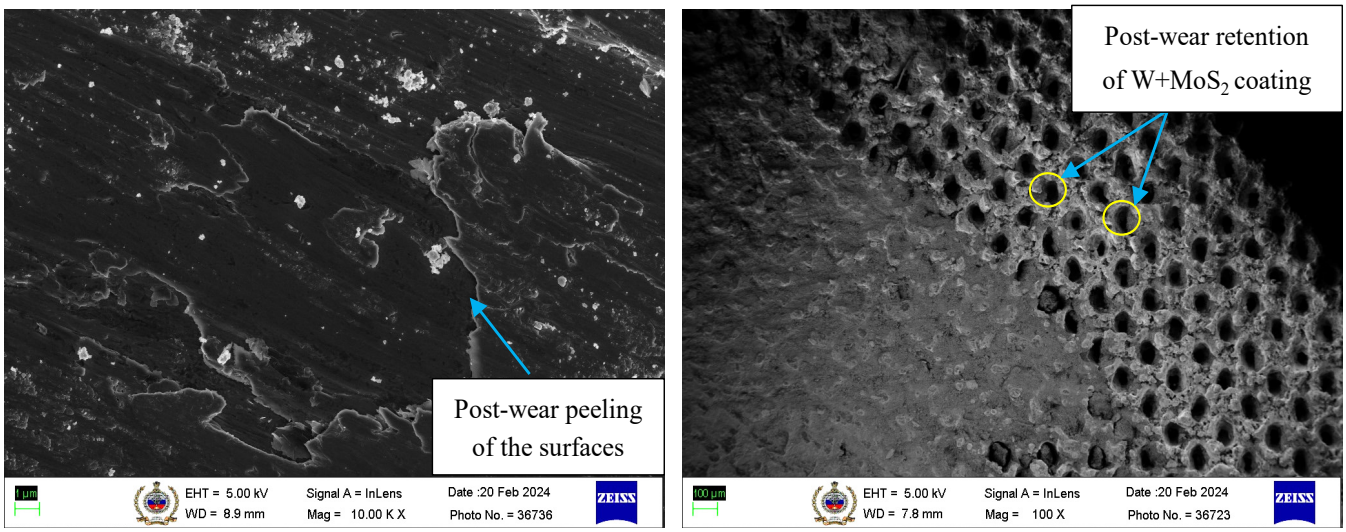


Figure 11. **(a)**. SEM images of untreated SG cast iron specimens after wear testing, **(b)** SEM image of a W+MoS_2 laser cladded specimen after wear

indicating a smooth and consistent coating over the SG cast iron specimen. The combination of tungsten (W) and molybdenum disulfide (MoS_2) may result in a dense and protective layer, crucial for enhancing wear resistance. The pores present are expected to assist in stress distribution during wear and may act as reservoirs for MoS_2, which possesses inherent lubricating properties. At 100x magnification, the image provides an overview of the surface's uniformity while revealing micro-scale features of the laser-cladded layer. The dense, uniform cladding ensures the SG iron substrate has a wear-resistant surface suitable for industrial applications like hot rolling mills. The integration of MoS_2 introduces self-lubricating properties that reduce friction under operational conditions, while tungsten enhances the surface hardness.

In Figure 10(b), this image displays well-defined pores, indicating an even distribution of the laser cladding material. The coating includes a composite hard coating of WC-10Co-4Cr consisting of tungsten carbide (WC), cobalt (Co), and chromium (Cr), materials known for their high hardness, ductility, and corrosion resistance.

At 500x magnification, the pores show precise distribution with consistent measurements, playing a significant role in wear performance and friction reduction. The combination of WC, Co, and Cr enhances the mechanical robustness of the substrate, ensuring it can withstand high-friction environments. The consistent size and distribution of pores contribute to stress distribution and lubricant retention, which is crucial for maintaining long-term wear resistance and tribological characteristics of substrates subjected to friction and wear.

The untreated worn SG Cast Iron sample after pin-on-disk wear tests showed significant signs of wear and peeling off, as shown in Figure 11(a). The rough surface with clear wear tracks indicates substantial material removal due to abrasive forces. Visible debris is scattered across the surface, highlighting the poor wear resistance of the untreated sample.

At 10,000x magnification, the image provides a detailed observation of the wear mechanisms and surface damage. The untreated SG iron surface demonstrates poor wear resistance under abrasive conditions, confirming the necessity of surface treatment. The roughness and debris present indicate considerable material loss, a critical issue in industrial applications like hot rolling mills, where continuous exposure to friction causes degradation of the contact surfaces subjected to wear.

As shown in Figure 11(b), the laser-cladded surface exhibits far less wear loss compared to the untreated counterpart, indicating the effectiveness of the W + MoS_2 surface modification coating in minimizing wear. Despite undergoing a wear test, the specimen with a laser-treated surface remained largely intact, demonstrating the durability of the tungsten cladding.

At 100x magnification, the macroscopic surface appears preserved chiefly, with fewer signs of significant wear debris. The W + MoS_2 cladding effectively protects the SG iron substrate, as evidenced by the smoother surface and lack of substantial debris. The reduced wear results from the hard tungsten layer and the lubricating properties of MoS_2, which lower friction and heat generation together, enhancing durability in high-wear environments.

4.0 Summary

The study of CFD Simulation and Surface Modification of SG Cast Iron Substrates with Hard Coatings presents an insightful investigation into surface engineering using tungsten coating deposited by Fiber laser cladding, particularly for hot rolling applications. The comparison between tungsten-coated and untreated SG cast iron surfaces offers valuable insights into thermal behaviour during rolling processes, highlighting temperature reduction in the coated surface and enhanced heat flux properties. The experimental validation, mainly through pin-on-disc wear and microhardness tests, validates the CFD findings. The SEM analysis of the wear patterns on laser-treated samples versus untreated specimens demonstrated a clear improvement in wear resistance for the tungsten-coated samples. These findings suggest the practical implementation of this technique for industrial applications in steel production to improve the service life of hot rolling rolls, leading to improvement in steel production.

5.0 Conclusions

The following conclusions are drawn from the comparative analysis of untreated and tungsten laser-cladded SG iron rollers based on CFD simulations and experimental trials,

- Tungsten-cladded rollers showed a 10-18 % improvement in heat dissipation compared to untreated rollers. The enhanced cooling pattern resulted from the higher water volume fraction and better water adherence, leading to more efficient heat transfer and stable temperature distribution on the tungsten-coated roll surface.
- The W+MoS_2 and WC-10Co-4Cr laser cladding significantly improved the wear resistance of SG iron rollers. The uniform cladding layers with well-distributed pores played a crucial role in reducing friction, minimizing wear and distributing stress more evenly under operational conditions.
- The self-lubricating properties of MoS_2 combined with the hardness of tungsten reduced friction and wear debris, resulting in smoother surfaces after wear tests. The W+MoS_2 laser-cladded SG cast iron specimens exhibited far less wear than untreated rollers, indicating their durability in high-stress environments like hot rolling mills.
- The tungsten cladding also enhanced the thermal stability of the rollers by maintaining a more uniform surface temperature during high-temperature operations, as observed in the CFD simulations. This improvement prevents thermal fatigue and extends the operational lifespan of the rollers.
- The combination of hard tungsten coatings and the lubricating effect of MoS_2 makes the laser-cladding rollers more suitable for long-term use in industrial applications. These modifications contribute to longer service life, better operational efficiency and reduced maintenance costs.

6.0 Future Scope

The next part of the research includes the ultrasonic processing of nanoscale powders like hBN, which are encapsulated with Ni and MoS2. These laser-textured nanocomposite coatings may improve wear resistance and reduce frictional coefficient due to self-lubricating substrates engineered with laser and deposited with coatings like tungsten (W) and solid lubricants like MoS_2.

Another experimental work is planned to develop a method of surface modification using High-Velocity Oxygen Fuel (HVOF) using WC-10Co-4Cr coating on SG Cast Iron substrates, which was analyzed for improvement in microhardness and wear resistance. The effect of laser surface texturing as a presetting operation for better adhesion of WC-10Co-4Cr coating using HVOF is part of our next step in this research work.

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