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# TO STUDY THE BEHAVIOR OF THERMAL SPRAY COATING ON EROSION WEAR OF BOILER TUBE

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**Abstract -** *The purpose of the present study was to investigate the effectiveness of (Cr3C2-35%NiCr) +5%Si cermet coatings in reducing damage caused by erosion in boiler applications. To achieve this, the coatings were applied onto a Fe based T22 steel substrate. Erosion studies were then conducted on both uncoated and HVOF coated steels using an air-jet erosion test rig in accordance with ASTM G-76 standard. The experiments were carried out at a velocity of 30 m/s and at different impingement angles of 30°, 60° and 90° using silica sand particles ranging in size from 150 to180 µm as erodent. The evaluation process involved analyzing weight-loss data and volumetric steady state erosion rates for different coatings and substrate alloys. The results indicated that bare T22 steel followed ductile erosion mode, while (Cr3C2-35%NiCr) +5%Si coating exhibited mixed behavior respectively. By utilizing these findings, it is possible to improve the durability of boilers through the use of effective cermet coatings that can reduce damage caused by erosion. This research provides valuable insights into the development of materials that can withstand harsh conditions, which is essential for ensuring long-term performance and reliability in industrial applications.*

***Key Words***: High Velocity Oxy-Fuel, Solid particle erosion, Cermet's, Surface analysis and boiler tubes.

## 1.OVERVIEW OF THERMAL SPRAY COATING

Thermal spray coating is a highly adaptable surface engineering method that involves applying coatings of various materials onto a substrate. The process begins with the careful selection of coating materials, which can range from metals and ceramics to polymers and composites, depending on the desired properties of the final product. Prior to coating, meticulous preparation of the substrate surface is essential to ensure optimal adhesion. The actual thermal spray process encompasses several techniques, including flame spray, plasma spray, HVOF spray, electric arc spray, and cold spray, each with its unique approach to heating and propelling the coating material onto the substrate. Multiple layers of coating may be built up to achieve the desired thickness and properties, with each layer typically allowed to cool and solidify before the next is applied. Post-treatment processes such as machining or heat treatment may follow to further refine the coating's characteristics. The versatility and effectiveness of thermal spray coatings make them invaluable in industries like aerospace, automotive, energy, manufacturing, and electronics, where surface protection and enhancement are paramount.

**Figure-1: Thermal Spray Coating**

## 2.PRINCIPLES OF THERMAL SPRAY COATING

The principles of thermal spray coating revolve around the fundamental processes involved in depositing a material onto a substrate to enhance its properties or protect it from environmental factors. Here are the key principles:

A. **Material Selection:** The choice of coating material depends on the desired characteristics of the final product. Factors to consider include mechanical properties, corrosion resistance, wear resistance, thermal conductivity, and cost.

B. **Surface Preparation:** Proper surface preparation is crucial for ensuring adhesion between the substrate and the coating. This may involve cleaning, grit blasting, or other surface treatments to remove contaminants and create a roughened surface for improved bonding.

C. **Thermal Energy Source:** Thermal spray processes rely on various energy sources to heat the coating material to a molten or semi-molten state. This can include combustion flames, plasma arcs, electric arcs, or high-velocity gas streams, depending on the specific method used.

D. **Material Deposition:** Once the coating material is heated to the appropriate temperature, it is propelled onto the substrate surface. This can be achieved through the use of compressed air, inert gases, or a combination of gases, depending on the thermal spray technique employed.

E. **Coating Formation:** As the molten or semi-molten particles of coating material impact the substrate surface, they rapidly cool and solidify, forming a dense and adherent coating layer. The deposition process is typically repeated multiple times to build up the desired coating thickness.

F. **Microstructure and Properties**: The microstructure and properties of the resulting coating are influenced by factors such as the temperature and velocity of the spray particles, the substrate material, and any post-treatment processes applied to the coating.

G. **Quality Control**: Monitoring and controlling key process parameters such as spray distance, spray angle, spray rate, and substrate temperature are essential for achieving consistent coating quality and performance.

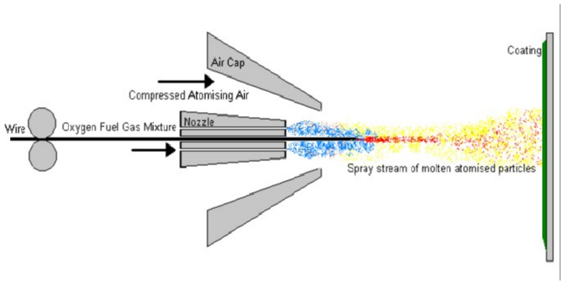

**Figure-2: Principle of Thermal Spray Coating**

## 3.IMPORTANCE OF EROSION WEAR IN BOILER TUBES

Erosion wear in boiler tubes is a critical concern for various reasons. Firstly, it poses a significant safety risk by weakening the structural integrity of the tubes, potentially leading to leaks or ruptures that endanger both personnel and equipment. Secondly, erosion wear diminishes the efficiency of boiler systems by reducing heat transfer efficiency, thereby increasing fuel consumption and operating costs. Thirdly, the expenses associated with repairing or replacing eroded tubes, along with the downtime for maintenance, can be substantial, impacting both operational budgets and production schedules. Additionally, erosion wear disrupts the smooth flow of fluids within the tubes, leading to fluctuations in pressure and temperature that adversely affect operational performance and reliability. Moreover, inefficient boiler operation due to erosion wear can result in increased emissions and environmental impact, potentially leading to regulatory compliance issues. Lastly, erosion wear shortens the lifespan of boiler components, necessitating more frequent replacements and upgrades, further impacting long-term costs and productivity. Hence, addressing erosion wear in boiler tubes through proactive measures is essential to ensure safety, efficiency, and longevity in boiler system operations.

## 4.IMPACT OF EROSION WEAR ON BOILER TUBE PERFORMANCE AND LIFESPAN

Erosion wear significantly affects the performance and lifespan of boiler tubes, impacting various aspects of boiler operation:

- **Performance Degradation:** Erosion wear alters the internal surface geometry of boiler tubes, disrupting the smooth flow of fluids and affecting heat transfer efficiency. This leads to decreased thermal performance, as the compromised tubes struggle to conduct heat effectively from the combustion gases to the water. Consequently, the boiler system operates less efficiently, requiring more energy input to achieve desired output levels.

- **Increased Maintenance Requirements:** As erosion wear progresses, boiler tubes become susceptible to leaks, cracks, or ruptures. This necessitates frequent inspections and repairs to maintain operational integrity and safety. Increased maintenance requirements not only incur costs but also result in downtime, impacting overall production and productivity.

- **Shortened Lifespan:** Erosion wear accelerates the degradation of boiler tubes, shortening their lifespan considerably. Tubes subjected to erosion wear may experience thinning of the wall thickness or develop pits and grooves, ultimately leading to premature failure. Early replacement of eroded tubes becomes necessary to avoid catastrophic failures and ensure continued operation, adding to maintenance expenses and downtime.

- **Safety Concerns:** The structural integrity of boiler tubes compromised by erosion wear poses safety risks to personnel and equipment. Leaking tubes can release high-pressure steam or hot water, causing steam explosions or fires. Moreover, erosion wear-induced failures may result in unplanned shutdowns, disrupting operations and potentially causing damage to surrounding equipment or infrastructure.

- **Environmental Impact:** Inefficient boiler operation due to erosion wear results in increased fuel consumption and emissions of greenhouse gases and pollutants. This not only contributes to environmental degradation but also may lead to regulatory non-compliance and associated penalties or fines.

## 5.IMPORTANCE OF INVESTIGATING THE BEHAVIOR OF THERMAL SPRAY COATINGS IN MITIGATING EROSION WEAR IN BOILER TUBES

Investigating the behavior of thermal spray coatings in mitigating erosion wear in boiler tubes is crucial for several reasons:

- **Enhanced Boiler Efficiency:** Erosion wear in boiler tubes can lead to reduced efficiency and increased downtime due to maintenance. By understanding how thermal spray coatings behave under erosive conditions, engineers can develop coatings that resist wear more effectively, thus improving boiler efficiency and reducing operational costs.
- **Extended Equipment Lifespan:** Erosion wear can significantly reduce the lifespan of boiler tubes, leading to frequent replacements and increased capital expenditure. Investigating the effectiveness of thermal spray coatings in mitigating erosion wear can help extend the lifespan of boiler tubes, reducing the frequency of replacements and increasing the overall reliability of the boiler system.
- **Safety Considerations:** Erosion wear in boiler tubes can compromise the structural integrity of the system, potentially leading to catastrophic failures and safety hazards. By studying the behavior of thermal spray coatings, engineers can develop coatings that not only resist wear but also maintain the structural integrity of the tubes, thereby enhancing safety in boiler operations.
- **Environmental Impact:** Boiler downtime due to erosion wear can result in production delays and increased emissions if alternative, less efficient boilers are used as backups. By minimizing erosion wear through effective thermal spray coatings, companies can reduce their environmental footprint by maintaining optimal boiler efficiency and minimizing emissions.

## 6.METHODOLOGY

In this research work, we have used the High Velocity Oxy-Fuel for thermal spray coating on the steel boiler tube. The details of the methodology are given below:

### 6.1.Parameter For HVOF Coating.

High-Velocity Oxygen Fuel (HVOF) coating, a process renowned for its ability to impart superior wear resistance, corrosion protection, and thermal insulation to surfaces, relies on a precise set of parameters for optimal performance. These parameters encompass several crucial aspects. Firstly, the choice of powder material, ranging from tungsten carbide to ceramic compositions, dictates the coating's properties. Particle size distribution must be carefully controlled to ensure uniformity in coating thickness and surface finish. The selection of fuel gas, such as hydrogen or propane, influences combustion flame temperature and velocity. Oxygen flow rate regulates combustion intensity, while combustion pressure affects flame characteristics. Additionally, the spraying distance, traverse speed of the spray gun, and substrate preheating temperature play pivotal roles in determining coating density, adhesion, and microstructure. Proper cooling rates post-spraying are indispensable to prevent substrate overheating and ensure desired coating properties. Ultimately, meticulous control and optimization of these parameters are imperative for achieving consistent coating quality and performance across diverse applications.

**Table-1: Parameter For HVOF Coating.**

| Serial Number | Parameter For HVOF Coating. | Value |
|---|---|---|
| 1.0 | Flow rate of the Oxygen | 195 litre per min |
| 2.0 | Flow Rate of the Fuel | 55 to 65 litre per min |
| 3.0 | Flow Rate of the Air | 445 litre per min |
| 4.0 | Distance between Machine nozzle and Coating Surface | 167 mm |
| 5.0 | Feeding Rate of Powder | 26 gram per min |
| 6.0 | Pressure of the Fuel. | 665 kPa |
| 7.0 | Pressure of Oxygen | 973 kPa |
| 8.0 | Pressure of the Air | 565 kPa |

### 6.2.EROSION TEST CONDITIONS

"In erosion testing for HVOF coatings, several critical parameters must be carefully controlled to accurately simulate real-world operating conditions and evaluate coating performance. These parameters include the choice of erosive media, such as alumina or silicon carbide particles, which are selected based on their relevance to the application environment. Particle size and shape play crucial roles, influencing erosion rates and mechanisms, with typical sizes ranging from micrometers to hundreds of micrometers. The velocity of the erosive media is a key factor, mirroring high-velocity impacts typical in HVOF-coated components. Impingement angle, substrate material, coating thickness, and environmental conditions are also vital considerations in designing erosion tests. By meticulously controlling these parameters and employing standardized testing methods, researchers and engineers can gain valuable insights into the erosion resistance and durability of HVOF coatings for various industrial applications."

**Table-2: Condition for the Erosion Test.**

| Serial Number | Parameter For HVOF Coating. | Value |
|---|---|---|
| 1.0 | Flow rate of the Oxygen | 195 litre per min |
| 2.0 | Flow Rate of the Fuel | 55 to 65 litre per min |
| 3.0 | Flow Rate of the Air | 445 litre per min |
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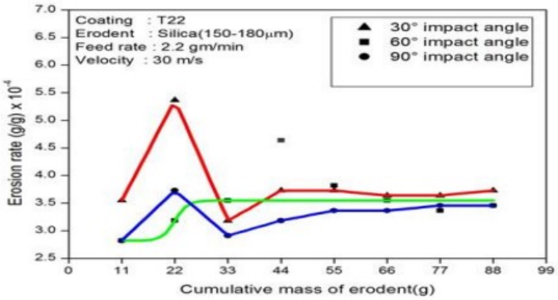
| 8.0 | Pressure of the Air | 565 kPa |

## 7.RESULT AND ANALYSIS

In this section of the result and analysis, we will see result after apply the High Velocity Oxygen Fule (HVOF) at the erosion metal by applying coating layer of the metal at the different angle that is mensioned in the chapter-03. The details of the results are given below.

### 7.1.VARIATION OF THE INCREMENTAL EROSION RATE WITH THE CUMULATIVE WEIGHT OF THE ERODENT FOR UNCOATED T22 STEEL.

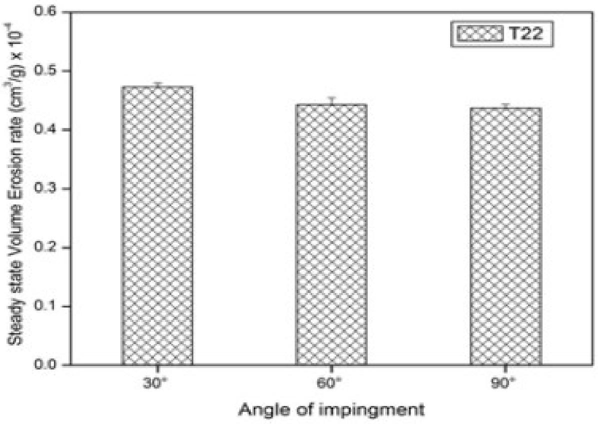
Understanding the variation of the incremental erosion rate with the cumulative weight of the erodent is crucial in evaluating the erosion resistance of materials like uncoated T22 steel. Typically, erosion testing involves subjecting the material to a stream of abrasive particles (erodent) under controlled conditions and measuring the erosion rate at different stages of erosion. Initially, the incremental erosion rate for uncoated T22 steel is relatively low, but as the cumulative weight of the erodent increases, it exhibits an initial steep rise due to the removal of surface layers and the onset of material degradation. Following this, a transitional phase occurs where the erosion rate increases steadily but at a slower rate, indicating the continued removal of surface material and the exposure of underlying layers with varying erosion resistance. Eventually, the erosion rate stabilizes to a relatively constant value in a steady-state stage, indicating an equilibrium between material removal and protective mechanisms such as work hardening or oxide layer formation. However, prolonged erosion exposure may lead to a failure stage characterized by a sharp increase in the erosion rate, signifying significant material loss and potential structural failure. Understanding these erosion behaviors informs strategies to enhance erosion resistance through material modification, surface treatments, or protective coatings.



**Graph-1:Variation of the Incremental erosion rate with the cumulative weight of the erodent for uncoated T22 steel.**

### 7.2.STEADY STATE VOLUME EROSION RATE OF UNCOATED T22 STEEL.

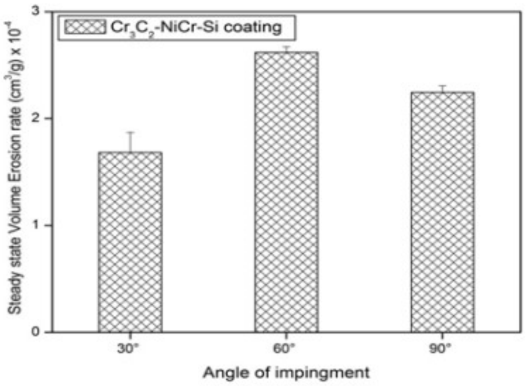
During erosion testing, the erosion rate is typically measured by quantifying the mass loss or volume loss of the material over a specified period of time. To obtain the steady-state volume erosion rate of uncoated T22 steel, researchers or engineers would typically conduct erosion tests using relevant parameters such as fluid velocity, temperature, and particle characteristics that are representative of the actual operating conditions. The erosion rate can then be calculated by dividing the volume loss of the material by the exposure time. It's important to note that erosion rates can vary significantly based on the specific conditions of the application, so experimental testing under conditions relevant to the intended use is essential for accurate predictions.



**Graph-2:steady state volume erosion rate of uncoated T22 steel.**

### 7.3.STEADY STATE VOLUME EROSION RATE WITH COATED.

The thickness of the coating is a critical factor in providing protection against erosion, as thicker coatings create a stronger barrier between the substrate and erosive particles. Additionally, the adhesion between the coating and the substrate is essential to ensure the coating remains intact when subjected to erosive forces. It is important to consider the properties of the erosive environment, such as fluid velocity, temperature, particle size, and impingement angle, as they can impact erosion rates. Conducting experimental tests under relevant conditions is necessary to accurately quantify erosion rates, which in turn allows for the optimization of coating design tailored to specific applications. By understanding and carefully considering these factors, engineers and researchers can develop coatings that effectively protect against erosion and extend the lifespan of various materials in different environments.



**Graph-3:steady state volume erosion rate with coated.**

### 8.CONCLUSION

High velocity oxy-fuel thermal spraying with oxygen and liquid petroleum gas as the fuel gases have been used successfully to deposit Cr3C2-35%(NiCr) + 5% Si alloy coatings on boiler tube steels. LPG fuel gas is cheap and readily available as compared to other fuels used for HVOF spraying. The (Cr3C2-35% NiCr) + 5% Si coating material behaves neither as purely ductile nor purely brittle as a function of impact angle and has a composite behavior whereas the morphology of the eroded surface point out grooving of binder phase, cratering. Platelet formation and particle pull-out that are prevalent in the coatings. The grooves in the binder region act as failure initiating concentrators and small carbide grains crumble off uncrushed, whereas the main mechanism of large grains failure is chipping.

Substrate T22 steel exhibit lower steady state volume erosion rate in comparison to all the HVOF coatings under similar test conditions. The higher hardness ratio between silica erodent particle and substrate steel might have caused the penetration of silica particles into the surface which bestow some shielding effect against impacting particles leading to lower wear loss.

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