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NiGrFeS HVAF Coating for Cold Rolled Steel Substrate: Microstructure Characteristics and Properties

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Abstract

Using air as the oxidizing gas, the High Velocity Air Fuel spray technique, often known as HVAF, sprays high velocity flames. The idea behind this novel approach is to use particle temperatures below or near their melting point while maintaining high particle velocities, allowing for plastic deformation at impact and coating development. In spite of research on HVAF coating having been conducted in the past, the issues of coating quality and surface finish are still a work in progress. According to the authors, this represents the first instance that NiGrFeS has been used for producing HVAF coatings on cold rolled SAE1008 steel designated substrate. This paper demonstrates the characterization of HVAF sprayed NiGrFeS coating on ASTM 1008 cold rolled steel as a substrate to improve surface properties for diversity of applications. A combination of characterization techniques, such as XRD and SEM/EDAX procedures, were used to evaluate the samples. According to their mechanical and microstructural characteristics, the as-deposited coatings are described. Additionally, assessed were the porosity, microhardness, coating thicknesses, and coating density. Microhardness readings have indeed been reported to have decreased from the coating to substrate material. In comparison to traditional coating processes, High-Velocity Air Fuel (HVAF) coating methods provide coatings with superior characteristics.

Keywords: HVAF Coating, Scanning Electron Microscopy (SEM), XRD Technique

1.0 Introduction

New developments in spray gun technology led to the creation of the High-Velocity Air Fuel (HVAF) thermal spray. HVAF compresses the air and propane, in contrast to HVOF, which uses an oxy-fuel mixture. Despite the fact that it may seem like a minor alteration, it has a big impact on coatings. Two key advantages over HVOF are higher spray rates and lower spray temperatures. Coatings are frequently applied to parts, containers, and constructions using the HVAF thermal spray process to prevent corrosion, wear, and discoloration. HVAF spraying systems were developed with the main objective of improving coating performance while reducing operational expenses. In order to spray a wider variety of materials, HVAF spraying uses a "warm spray" technique that is hotter than cold spraying but cooler than HVOF. The feedstock powder is melted in HVAF just above the materials melting point and below the vaporization temperature, similar to the other thermal spray processes with the exception of cold spraying. The choice of the spraying technique and the adjustment of the spraying

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process parameters require special consideration if thermal spray coatings are to provide effective protection against material deterioration. A dense and uniform structure is also necessary. Recent advancements in High Velocity Air Fuel Spraying (HVAF) technology and apparatus have improved coating quality and process uniformity. The HVAF applications not only entered the established High Velocity Oxygen Fuel spraying (HVOF) markets, but also created brand-new ones where HVOF was not feasible owing to a lack of essential characteristics or because the cost was prohibitive[3]. This means that the thermal spray society still has a limited understanding of contemporary HVAF procedures, and there is meagre data on the successes and failures of HVAF applications[4]. When dealing with high wear situations, the necessity for protection and the difficulty of assuring its sufficiency have both expanded intensely[5].

2.0 Materials and Method

SAE1008 cold rolled steel was chosen as the substrate material for the High Velocity Air Fuel (HVAF) process to create composite coatings. Table 1 provides information about the substrate materials chemical composition. The cylindrical steel samples were machined by cutting and turning into specimens with Ø7.5 to 25 mm length. The commercially available 308NS (NiGr) from Oerlikon Metco, Switzerland was obtained through M/s. Spraymet Surface Technologies Pvt. Ltd., Bengaluru, India; Ferrous Sulphide (FeS) was supplied by Jainson Labs India, Meerut; and Multi-Walled Carbon Nanotubes (MWCNT) was procured from Adnano Technologies, Shimoga, India. To make the different combinations, the weight percentages of NiGr and FeS were varied, and the ingredients were blended using a mechanical mixer. In comparison to conventional grit blasting with compressed air, surface preparation using HVAF technology boosts output rate by at least 5 times while reducing grit use by at least 10 times. Further, reducing the time for thermal spray coating is the requirement for the same setup for both coating-spraying and blasting when utilizing the same gun. The coating was performed at Spraymet Surface Technologies Pvt Ltd. using the Kermetico HVAF AK5 Compact System situated in Bengaluru, India. In Table 1, the coating deposition process parameters are presented.

For samples created using the HVAF coating technology, the following designation is given, as shown in Table 2.

Testing for density and porosity was done in order to evaluate the effectiveness of the technique that was used, which is primarily known for creating coatings with the least amount of porosity. Archimedes principle provides a practical and accurate method that aids in calculating density in accordance with ASTM C135-96(2022) standards, which is necessary to calculate the volume of an item with an irregular shape and is strategically in wider usage. Additionally, this is also termed and known as hydrostatic weighing. By using ASTM E2109-01 test procedures for calculating area percentage porosity in thermal sprayed coatings, porosity measurements were conducted. Sample transverse sections were prepared for optical microscopy according to the suggested method. The commercial software connected to the microscope was used to conduct a quantitative metallographic analysis. To ascertain physical characteristics, an image analyzer framework provides samples that have photographs of the microstructure. In the current work, micro-hardness measurements are conducted using a Buehler VH 1102 Vickers microhardness tester. The major uses of the Vickers hardness test method, also referred as a microhardness test method, are thin sections or case depth work. The Vickers method is used and is based on an optical measurement technique. In the

Table 1. The coating deposition process parameters

Parameters	Value
Working temperature	Around 1850°C
Spray powders	Up to 50µ
Deposition rate	5kg/hr
Nitrogen carrier gas	10 bar
Total power	80kW
Air pressure	7.5 bar
Propane pressure (Fuel)	6.5 bar

Table 2. Samples created using the HVAF coating technology

Si. No.	Sample Description	Sample Identification
1.	100wt%	AF1
2.	50wt% + 50wt%	AF2
3.	50wt% + 49wt% + 1wt%	AF3
4.	75wt% + 24wt% + 1wt%	AF4
5.	25wt% + 74wt% + 1wt%	AF5

ASTM microhardness test process, a diamond indenter is utilized to generate an indentation that can be measured and converted into a hardness value as per ASTM (E-384). Porosity measurements was carried out by ASTM E2109-01 test methods for determining area percentage porosity in the thermal spray coatings. On the coated cross-section of every sample, ten random impressions were created. Finally, using standards based on IS:3203 - 1982, coating thickness was evaluated on the HVAF designated samples of (AF1 to AF5). The nondestructive semi-quantitative method of Positive Material Identification (PMI), portable X-ray Fluorescence (XRF), was used to identify the materials chemical coating composition according to the ASTM E1476-04 standards.

3.0 Results and Discussion

The optical emission spectrometry procedure specified in ASTM E415-21 was used to validate the substrate materials composition, and the elements found are listed in Table 3. The base material was confirmed to be cold-rolled SAE 1008 steel. The microhardness reflects the microstructure, the physical and mechanical properties of the substrate and coating, which are in turn impacted by the materials and manufacturing processes used to produce them.

Hardness is a property that can be regarded of as being variable in some parts of the coating due to probable material heterogeneities. As a result, it's crucial to consider the state of the surface preparation, the components that will be checked, as well as the total number of indentations made, while assessing this feature. To examine the microstructural features of the coatings on the mild steel substrate, an optical microscope, an image analyzer, and a scanning electron microscope were used. The Figure 1 shows a schematic illustration of an HVAF spray system.

Table 3.

Element Content	Percent%	Specification of SAE 1008 in %
Iron	99.201	99.31-99.7
Carbon	0.087	0.1 Max
Silicon	0.234	Not Specified
Manganese	0.421	0.3-0.5
Phosphorous	0.031	0.04 Max
Sulphur	0.026	0.05 Max

The coating microstructure is also impacted by spray distance, particle temperature, and velocity. Each of the features that make up a coatings microstructure plays a vital role in determining the wellness of coatings performance in various test scenarios. One of the characteristics is porosity, which varies accordingly on the processing technique utilized. With the minimal possible of porosity, the HVAF deposition process is acclaimed for generating dense coatings. The maximum amount of porosity along the cross-sectional area of all the coatings was found to be on average less than 1% using software for image analyzer. The lower value of porosity created for the HVAF sprayed coatings may be attributed to the increased kinetic energy of metal powders and the melting behavior shown by the particles. A practically porous-free coating is created when the partially melted material strikes the substrate intensely. The images depict the morphology of the powders that were purchased, and both analysis and the specifications that the powder supplying companies supplied confirmed the particle size. Figure 2 and 3 illustrates the usual morphology of spray powders that have been categorized into different sizes. Every powder has a predefined form; it has been found. SEM images were used to measure particle size, and the data sheet that was produced was consistent with the findings. The NiGr and FeS particle sizes were estimated to be between 45 and 60 microns. Due to their heterogenous morphology, a variety of techniques can be employed to develop powders that are suitable for

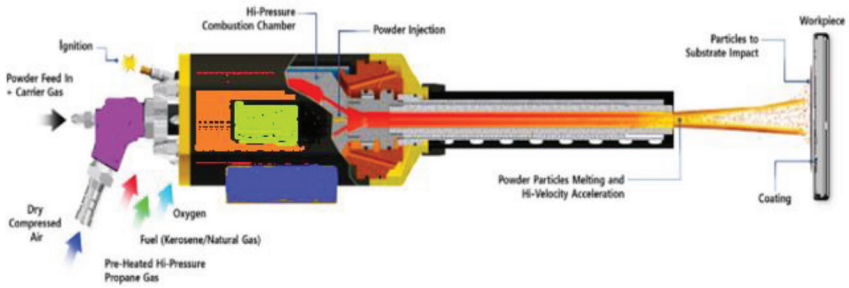


Figure 1. HVAF operational system.

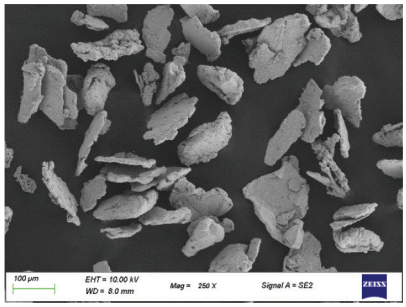


Figure 2. SEM morphology of 308NS(NiGr) powder.

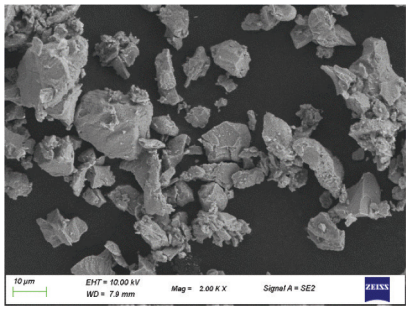


Figure 3. SEM morphology of FeS powder.

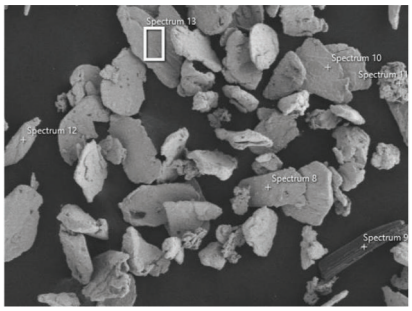


Figure 4. **(a)** Spectrum of 308NS (NiGr).

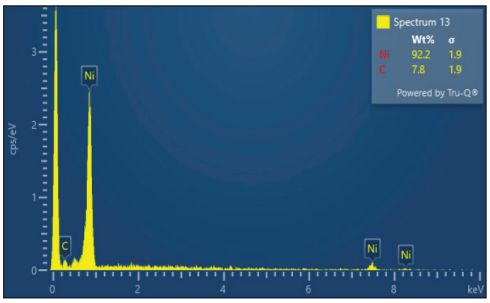


Figure 4. **(b)** SEM with EDAX of 308NS (NiGr) powder.

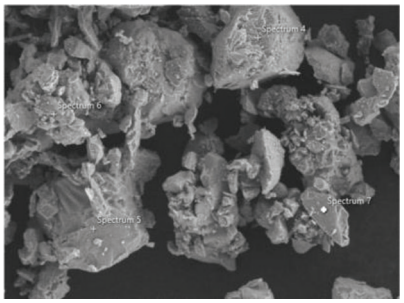


Figure 5. **(a)** Spectrum of FeS powder.

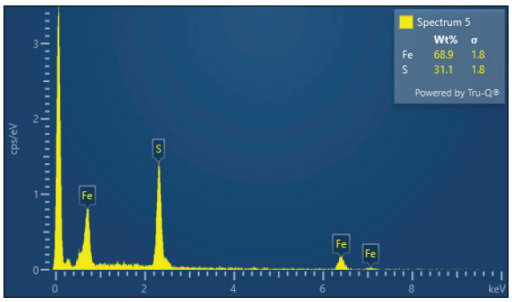


Figure 5. **(b)** SEM with EDAX of FeS powder.

Table 4.

Si. No.	Sample Identification	Hardness Value (HV1)	Coating Thickness (μm)
1.	AF1	285	350
2.	AF2	276	310
3.	AF3	280	340
4.	AF4	271	325
5.	AF5	267	300

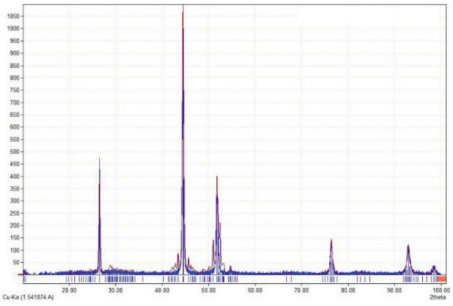


Figure 6. XRD of 308NS(NiGr) powder.

thermal spraying. Ball-shaped grains are the ideal since they increase looseness and make it simpler to enter the spray stream convincingly. The spherical form of the whole grain also allows for even heating as it is suspended in the spray stream.

SEM measurements of powder particles are made using the Energy-Dispersive X-ray Analysis (EDAX) technique. A modern SEM typically comes with an EDS X-ray spectrophotometer, which is used in this approach

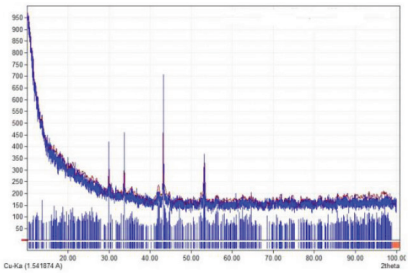


Figure 7. XRD of FeS powder.

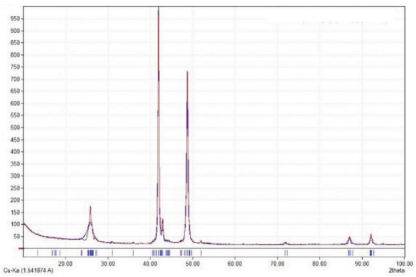


Figure 8. XRD of MWCNT.

to evaluate the particles by activation. After maintaining the appropriate instrumental conditions, this approach provides accurate findings for element detection in addition to determining their concentration. Figures 4(a, b) and 5(a, b) respectively exhibit NiGr and FeS powders utilized in the HVAF process that have had their SEMs combined with EDAX.

The high-intensity peaks of nickel, graphite (in the form of carbon), iron, the Sulphur phase, and Multi-Walled Carbon Nano-Tubes (MWCNT) in the form of carbon can be seen in the XRD analysis of the powder that was received, as shown in Figures 6, 7, and 8 sequentially.

Figure 9 displays micrographs of the coatings on the SAE1008 cold-rolled steel substrate. This provides a crystal-clear indication of the surface contact and coating details, together with any pertinent characteristic features.

Microhardness value measurements are made at the point of contact between the coating and substrate. The micro hardness profile of each coating is shown in Figure 10 as a function of distance from the coating substrate contact. The microhardness of the coatings is found to vary along the cross-section, and a further notable increase in micro-hardness values were measured on the substrate region more closely adjacent to the coating substrate-interface. Table 4 lists the hardness values and coating thickness measurements.

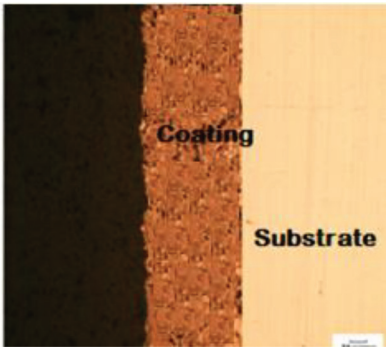


Figure 9. Coating on the substrate**.**



Figure 10. Hardness indentation on coating.

4.0 Conclusion

The most used feedstock for thermal spraying is powder. The effectiveness of feeding and injection systems, as well as deposition and coating build-up mechanisms, is significantly influenced by the form of the powder. Microparticles considerably avoid feeding and injection obstructions due to their flowability. Furthermore, spherical particles have predictable outcomes because of their homogenous morphology and regulated function. This study intends to present the findings of the ongoing research in the aforesaid thermal spray coating on SAE1008 cold rolled steel substrate using High-Velocity Air Fuel (HVAF) thermal spray system.

- The requirements for the HVAF spraying process were successfully met by manually combining and agglomerating a nickel-graphite or ferrous sulphide or MWCNT feedstock.
- The micrographs of the coated cross-sections showed excellent homogeneity and consistency.
- The coating had minimal porosity, great substrate contact, and little to no oxide content. When measured in accordance with ASTM standards, the layer has a thickness of between 300 and 350 microns. No non-melted or semi-melted particles were present in the coatings.
- After evaluation, it was determined that the coating and substrate had microhardness values of 275.8 HV1 and 98 HV1, respectively. This elucidates the coating is multiple times as hard as the substrate.
- The microstructure of the coating is uniform, dense, has the fewest pores, and is homogeneous and consistent.

- The coating was found to have a porosity value of less than 1%.

It may be clearly concluded that the HVAF composite spray coatings might effectively replace chrome plated coatings, wherein manufacturing process could be halted due to its hazardous nature.

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