iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH
IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 13 Issue: II Month of publication: February 2025

DOI: https://doi.org/10.22214/ijraset.2025.66832

Effect of Thickness on Microstructure and Mechanical Properties of Inconel Superalloy using Thermal Spray Coating

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***Abstract:** The effect of deposit thickness on the microstructure and the mechanical properties of Inconel 718 (IN718) fabricated by thermal spray deposition was systematically investigated in both as- deposited (AD) and homogenization + solution + aging (HSA) treated conditions. Results indicate that deposit thickness for thin parts has a more significant impact on the microstructure and subsequent room (RT) and elevated temperature (650 °C) tensile properties compared to thick parts. Applying HSA treatment can effectively homogenize the microstructure. Thermal spray coatings are deposited on Inconel superalloy 718 using a highvelocity oxy-fuel spray process. The microstructure, wear resistance and mechanical of the coatings are to be systematically studied. SEM analyses revealed that grain refinement occurred within the coatings and substrates (near the substrate-coating interface), which could be attributed to strain accumulation and fragmentation process. Hardness values are determined for Inconel 718 and analyzed for various thicknesses of the coatings. The wear results are to be studied for both increased sliding velocity and normal load which will lead to higher specific wear rates, which could result from the combined effects of adhesive wear, abrasive wear, and thermal softening. The results present in the current study show the capability of the thermal spray deposition process to manufacture homogeneous components with varying thickness for high-temperature application after a proper heat treatment, with regard to their initial as deposited materials.*

***Key words:** Thickness, Microstructure, Mechanical Properties, Inconel Superalloy, Thermal Spray Coating*

I. INTRODUCTION

Inconel superalloys, renowned for their exceptional high-temperature strength, corrosion resistance, and mechanical properties, have found extensive applications in aerospace, gas turbine engines, and other challenging environments. To further enhance their performance and longevity, researchers and engineers have been exploring advanced surface modification techniques. One such technique, thermal coating, has gained significant attention due to its ability to improve the microstructure and mechanical properties of Inconel superalloys. The microstructure of a material, including grain size, distribution, and orientation, plays a pivotal role in determining its mechanical properties. By applying thermal coatings of varying thicknesses onto Inconel superalloys, researchers aim to influence the microstructural evolution during the coating process. Understanding how the thickness of the thermal coating affects the microstructure is crucial for optimizing the manufacturing process and tailoring the material properties to specific applications. In recent years, the aerospace, automotive, and energy sectors have witnessed a surge in demand for materials capable of withstanding extreme temperatures, corrosive environments, and high mechanical stresses. Inconel, a family of nickel-based superalloys, has emerged as a popular choice due to its remarkable combination of high-temperature strength, oxidation resistance, and corrosion resistance. To enhance its performance and longevity, thermal spray coating techniques have been extensively employed, allowing for the application of thin protective layers on various components.

II. LITERATURE REVIEW

1) Vaishnavi Kohale, Ganesh kakandikar, et al. [1]

The investigation on mechanical behavior of Inconel 718 manufactured through additive manufacturing is observed. The effect of heat treatment on mechanical properties is observed using UTS and Hardness as performance and heat treatment's impacts on microstructure, process-induced flaws, and microstructural behavior were investigated using Scanning Electron Microscopy (SEM). The samples are simulated using the SIMUFACT ADDITIVE to calculate the yield stress. The microstructure and tensile characteristics of Inconel 718 superalloy were seen to be improved by ageing treatment.

2) Yingli, jaromir dlouhy, Martina koukolikova, Abhilash kirana, et al. [2]

the effect of thickness deposited on Inconel 718 super alloy (IN718) to study microstructure and mechanical properties at ambient and elevated temperatures for by directed energy deposition method. By varying thickness samples of (50 to 200 microns) were consider for experiment at around 650 °C with heat-treated conditions. The results show that the columnar dendritic grain structure and size is observed for all samples.

3) S. Ramesh babu, M. Puviyasasan, et al. [3]

Performed, mechanical, microstructural and fracture studies on Inconel 825–SS316L functionally graded wall fabricated by wire arc additive manufacturing. The following conclusions are arrived: The fabricated Inconel 825 specimen has both continuous and discontinuous cellular dendritic microstructures, whereas the SS316L specimen has austenite and 5% delta ferrite in its microstructure. Both Inconel 825 and SS316L tensile fractography revealed considerable plastic deformation, indicating a ductile mode of fracture

III. OBJECTIVE

The specific objective of this project was

1) To investigate the influence of varying thicknesses of Inconel superalloy thermal spray coatings on microstructural characteristics.
2) To evaluate the relationship between coating thickness and mechanical properties such as hardness, tensile strength, and fatigue resistance.
3) Optimize the coating thickness to achieve the desired combination of microstructural features and mechanical properties for specific applications
4) Explore the correlation between coating thickness, deposition parameters, and process conditions to establish guidelines for reliable coating thickness control.
5) Conduct comparative studies with alternative coating techniques to highlight the advantages of thermal spray coating in terms of microstructure and mechanical performance across different thickness ranges.

IV. PROPOSED SYSTEM

A. Material: Inconel Superalloy

INCONEL alloy is a solid-solution, strengthened, nickel- chromium-cobalt molybdenum alloy with an exceptional combination of high-temperature strength and oxidation resistance. The alloy also has excellent resistance to a wide range of corrosive environments, and it is readily formed and welded by conventional techniques.

Inconel Superalloy Composition: Inconel comprises a nickel-chromium-molybdenum alloy.

Nickel	44.5 min.
Chromium	20.0-24.0
Cobalt	10.0-15.0
Molybdenum	8.0-10.0
Aluminum	0.8-1.5
Carbon	0.05-0.15
Iron	3.0 max
Manganese	1.0 max
Silicon	1.0 max
Sulfur	0.015 max
Titanium	0.6 max
Copper	0.5 max
Boron	0.006 max

Table 1 - Limiting Chemical Composition, %, of INCONEL alloy

ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor: 7.538
Volume 13 Issue II Feb 2025- Available at www.ijraset.com

B. Sample Pieces

Each sample consists of 2mm thickness, 30mm height and 45mm length Total 11 samples, out of 1 sample without coating and 5 are Epoxy 1 coating with 1mm, 2mm, 3mm thickness and other 5 are Epoxy 2 coating with 1mm, 2mm, 3mmthickness.

Fig:1. Inconel Sample piece

C. Thermal Spray Process

Epoxy coating using high velocity oxy fuel (HVOF): The process of applying epoxy coating using high velocity oxy fuel (HVOF) involves heating a powdered epoxy resin and accelerating it through a supersonic nozzle onto a substrate surface. The high velocity and heat of the HVOF process ensure a strong bond between the epoxy coating and the substrate.

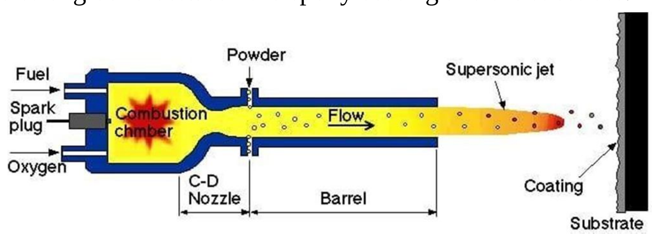

Fig 2. HVOC process

D. Testing of Material

Surface Roughness Testing using Talysurf: The roughness values Ra and Rz are measured using a profilometer gauge (Talysurf) in this experiment. With the use of a moving probe, a surface profilometer gauge is used to measure the roughness parameters with great precision.

Fig 3. Experimental Setup talysurf

E. Hardness Testing using Brinell hardness tester

Brinell hardness is determined by forcing a hardened steel or carbide ball of known diameter under a known load into a surface and measuring the diameter of the indentation with a microscope. We tested samples of different loading conditions.

Fig 4. Brinell hardness testing

V. RESULTS

1) We successfully tested surface roughness by using talysurf device. The achieved results are

Material	Profile	chieved values
Inconel Without coating	Ra Rz Rq	0.76µm 6.82µm 1.06µm
Inconel with epoxy1 coating	Ra Rz Rq	0.55µm 2.42µm 0.64µm
Inconel with epoxy2 coating	Ra Rz Rq	0.13µm 1.20µm 0.18µm

Table 2. Surface roughness Results

Hardness testing is done using Brinell hardness tester and the achieved results are mentioned in the below table.

VI. DISCUSSION

A. Surface Roughness (Ra) Analysis

The surface roughness, measured as Ra, is a critical parameter in determining the quality and performance of coatings on a substrate. In this study, three different samples were analyzed: the original Inconel sample, and samples coated with epoxy 1 and epoxy 2 coatings.

The results indicate that both epoxy coatings significantly improved the surface roughness compared to the original Inconel sample. Specifically, the epoxy 2 coating exhibited the best performance in achieving a very good surface finish, followed closely by the epoxy 1 coating. This suggests that both epoxy coatings effectively reduced the surface roughness, enhancing the overall quality of the coated surface. It's noteworthy that there was only a slight difference in roughness between the epoxy 1 coating and the original sample. This could imply that while epoxy 1 coating improves surface quality, it may not offer as significant an improvement as epoxy 2 coating in terms of surface roughness.

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
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B. Hardness Testing

Hardness testing is crucial for evaluating the mechanical properties and durability of coatings under different loading conditions. In this study, the original Inconel sample and samples coated with epoxy coatings of varying thicknesses were subjected to hardness testing under different loads.

The results reveal that the original Inconel sample exhibited excellent performance in hardness testing, sustaining the applied loads without experiencing cracking or material failure. This indicates the inherent strength and resilience of the Inconel substrate material. However, the epoxy-coated samples showed varying degrees of performance under the same loading conditions. Specifically, the epoxy-coated samples with 2mm and 3mm thicknesses experienced damage, including cracking and material failure, under the applied loads. This suggests that thicker epoxy coatings may compromise the mechanical integrity of the coated material, leading to decreased hardness and increased susceptibility to damage.

Sample	Coating Thickness	Force	Time	Ball Dia	Size of Indentation	Status of coating
Original Sample	-	500	15 sec	10 mm	1mm	NO cracking
		1500	15 sec	10 mm	2mm	NO cracking
		3000	15 sec	10 mm	3mm	NO cracking
Epoxy 1.1	1mm	500	15 sec	10 mm	2mm	No crack
		1500	15 sec	10 mm	4mm	No crack
		3000	15 sec	10 mm	5mm	No crack
Epoxy 1.2	2mm	500	15 sec	10 mm	3mm	Initial Crack
		1500	15 sec	10 mm	3.2mm	Completely spoiled
Epoxy 1.3	3mm	500	15 sec	10 mm	-	Completely spoiled
		-	-	-	-	-
Epoxy 2.1	1mm	500	15 sec	10 mm	3mm	Initial cracking
		1000	15 sec	10 mm	3.1mm	Epoxy coating damaged
Epoxy 2.2	2mm	500	15 sec	10 mm	5mm	Crack
		1000	15 sec	10 mm	6mm	Coating damaged
Epoxy 2.3	3mm	500	15 sec	10 mm	-	Completely damaged

Table 3. Hardness test Results

VII. ADVANTAGES

1) Improved Performance
2) Enhanced Durability
3) Cost Efficiency
4) Tailored Applications
5) Process Optimization & Research Advancements

VIII. CONCLUSION

A. Surface Roughness (Ra)

Inconel Epoxy 2 Coating: Achieved the lowest average roughness (Ra), indicating a smoother surface compared to the other coatings and the original sample. This suggests that Inconel epoxy 2 coating provides effective surface smoothing. Epoxy 1 Coating: Followed Inconel epoxy 2 coating in terms of smoothness, indicating it is also effective in reducing surface roughness, though slightly less so than the Inconel epoxy 2 coating. Original Sample: Had the highest roughness among the tested surfaces, indicating the surface was the roughest in its untreated state. However, it still exhibited a slight improvement in roughness compared to the epoxy 1 coating.

B. Hardness Testing

Original Sample: Showed excellent resilience to cracking and breaking even under varying loads, indicating good inherent material strength. Epoxy Coated Samples:2mm and 3mm Thickness: Both experienced damage under applied loads, suggesting that thicker coatings may compromise the structural integrity of the material, leading to increased vulnerability. 1mm Thickness:Epoxy 1 Coating: Showed initial cracking at lower force levels compared to Inconel epoxy 2 coating, indicating it might have slightly lower resistance to load-induced damage. Inconel Epoxy 2 Coating: Exhibited better performance in withstanding applied loads without cracking, indicating its higher resilience

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