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Analysis of Bending Stresses On Coating Materials by Experimental and FE Method

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Abstract: **High Velocity Oxy-Fuel (HVOF) spraying of Inconel-718 powders on mild steel sheets is carried out. Three-point bending tests are carried out to examine the mechanical properties of the coating. Stress fields developed during the tests are simulated using Finite Element Method (FEM). ANSYS package is used to predict the stress field. Three- and two-dimensional modeling of the coating and substrate material are considered and the predictions of load–displacement characteristics are compared with the experimental results. Since two-dimensional predictions agree well with the experimental data, two-dimensional model is employed in the simulations. Consequently, crack initiation and propagation at coating and substrate material interface occurring may be determined, similarly above steps were carried out for different thickness and for different loading conditions of coating materials.**

Keywords: **Bending Stresses, Inconel-718, Coating materials, Mild Steel Substrate.**

1. INTRODUCTION

High velocity oxy-fuel (HVOF) deposition is widely used in industry as protective coating of various materials. In HVOF coating process, powders are inserted in a gas stream with a high flame temperature; therefore, the particles are heated rapidly and accelerated almost the same speed of gas jet. The velocity of the particle reaches well above the speed of sound before impacting onto the work piece surface. The splats (powder at molten state in the jet) make bonds to the substrate surface through mechanical locking onset of impacting. HVOF spraying can produce high quality and low porosity coatings, which may have good interface properties. Coating is a covering that is applied to an object. The aim of applying coatings is to improve surface properties of a bulk material usually referred to as a substrate. One can improve amongst others appearance, adhesion, wetability, corrosion resistance, wear resistance, scratch resistance, etc. They may be applied as liquids, gases or solids. The thermal spray is to melt material feedstock (wire or powder), to accelerate the melt to impact on a substrate where rapid solidification and deposit buildup occur.

High velocity oxy fuel (HVOF) coating is a thermal spray technique used to deposit protective coatings on a substrate. A blend of fuel (gaseous or liquid) and oxygen is injected into a torch and burned. The combustion products flow through a nozzle, that the stream of hot gas and powder is directed towards the surface to be coated. HVOF thermal spray applications are in the fields of Aerospace, Power generation, Automotive, Transportation / Heavy equipment, Printing and paper / pulp equipment, Glass manufacture, Metal processing, Textile machinery, General industry, Petrochemical, etc.

1.1 Coating material & Steel substrate;

Inconel 718 is a precipitation hard enable nickel-chromium alloy containing significant amounts of iron, niobium, and molybdenum along with lesser amounts of aluminum and titanium. A substrate material of Dimension 100*150*1.75 mm for coatings is manufactured from 12% Cr Mild Steel.

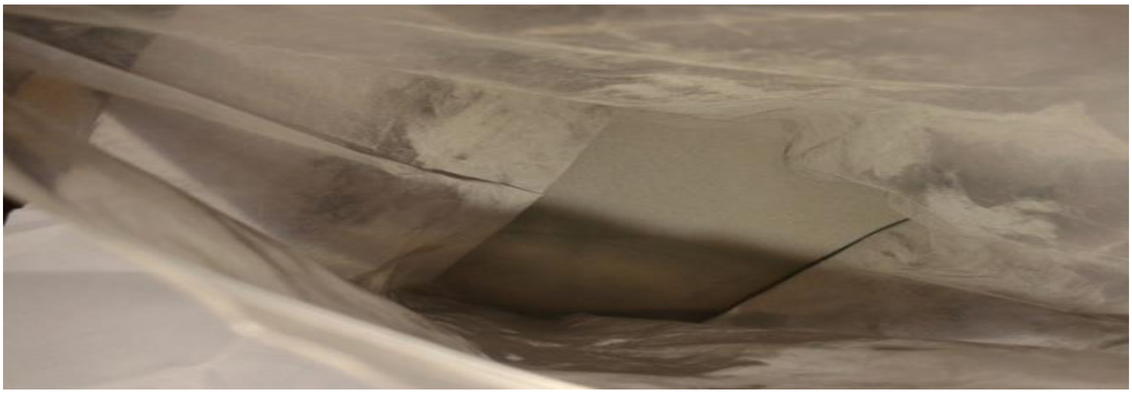


Fig.1 Inconel-718 Powder

Fig.2 Mild Steel substrate

The work carried out by various researchers for analysis of bending stresses on coating materials compiled and presented by A.F.M. Arif [1] on Three-point bend testing of HVOF Inconel 625 coating: FEM simulation and experimental investigation and they concluded the Stress fields developed during the tests and are simulated using Finite Element Method (FEM), Then Carolin Pfeiffer [2] miniaturized bend tests on partially stabilized EB-PVD ZrO_2 thermal barrier coatings, they studied the brittleness, stiffness and thickness of the top coat and complex microstructure and found the bending stresses by measuring strains and young's modulus of above said coating materials. Dr. C.S. Ramesh [3] carried work on Influence of forging on mechanical properties of Ni–P coated Si_3N_4 reinforced Al6061 composites and made a studies on the effect of forged alloy and their composites were subjected to microstructural studies, micro hardness and tensile strength tests. Y.C. Zhou [4] carried work on Fracture characteristics of thermal barrier coatings after tensile and bending tests and he proved that Substrate thickness has an important effect on the fracture characteristics of the TBC. Also P. V. Jadhav [5] carried work on Effect of surface roughness on fatigue life of machined component of Inconel 718, they observed that the specimens with lower surface roughness show higher fatigue life compared to higher surface roughness.

Fig.3 Grit blasting process in progress

2. METHODOLOGY

2.1 Grit Blasting Process:

Abrasive grit blasting is the process by which an abrasive media is accelerated through a blasting nozzle by means of compressed air. The grit blasting process is used to prepare all the samples for thermal spraying to achieve good bond between the coating and the substrate. The substrate namely Mild Steel (MS) have been grit blasted using the Alumina abrasives of particle size 80 microns using the grit blasting machine shown in fig.3. Compressed air of pressure 10 bar was used for all the blasting operations to obtain the desired roughness of the surfaces suitable for HVOF process.

Before

After

Fig.4 Grit blasted sample surface

High velocity oxy-fuel thermal spraying process

Fig.5 Key components of HVOF spray system

2.2 HVOF Coating Procedure:

The HVOF setup installed is shown in fig. The setup consists of gas cylinders, nozzle system, 10HP compressor and control panel. Before the spray process the following safety checks are followed.

- ✓ Check for gas leakages.
- ✓ Check for gas flow through the nozzle using the manual operation mode in the control panel.
- ✓ Ensure no clogging of nozzles.
- ✓ Ensure powder filling before powder carrier gas namely nitrogen is released into the powder unit.
- ✓ Water levels in the vapourising unit to be monitored and refilled if necessary before starting the spray processing.
- ✓ Ensure the temperature of the vapourising is at 70^0C before starting the spray processing.
- ✓ Check the levels of oxygen, nitrogen and LPG fuel before starting the spray process.

Inconel-718 powders were sprayed onto the grit blasted MS substrates a standoff distance of 40cm was maintained for all coating trials of samples. All the coating trials have been conducted using the following optimized process parameters. Thermal spraying parameter details as shown in table 1.

Table 1. Thermal spraying parameters

Oxygen Pressure (kPa)	Fuel pressure (kPa)	Air pressure (kPa)	Powder feed rate (m3/h)	Spray rate (kg/h)	Spray distance (m)
1030	600	715	0.78	6.25	0.27

Fig.6 HVOF Spraying Process

Fig.7 HVOF Coated Sample

2.3 Model Preparation:

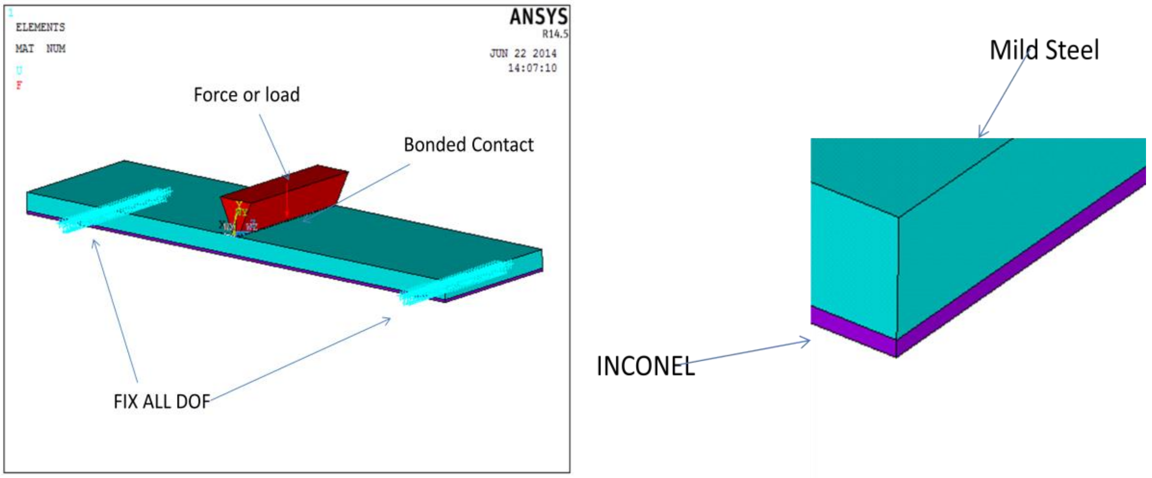


Fig.8 Experimental & Analytical Model

2.4 Geometric arrangement of the three-point bending test apparatus:

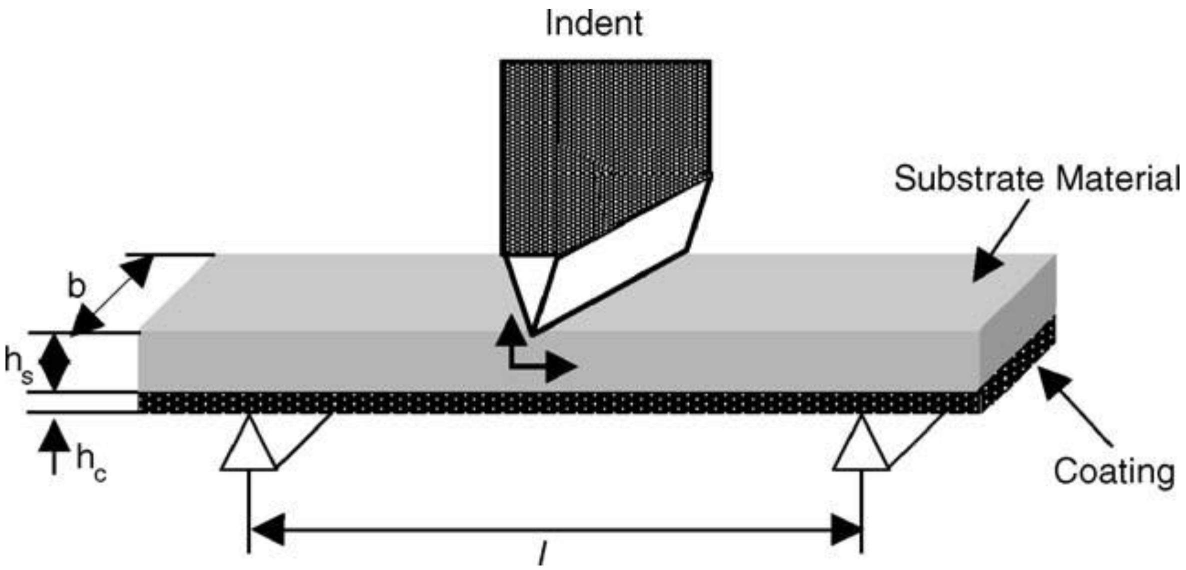


Fig.9 Geometric configuration of the Specimen

l (mm)	**b (mm)**	**h_s (mm)**	**h_c (mm)**	**P (N)**
44	150	1.75	0.25, 0.5,1	2000, 3000, 4000

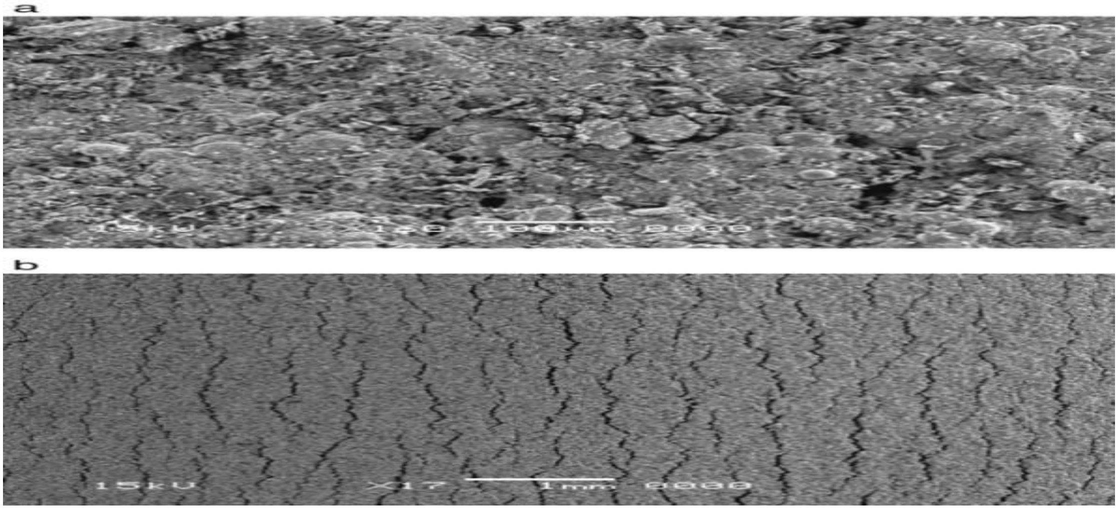
Bend tests were performed according to ASTM Standard Method E 290-77 with a guided-bed jig as described in ASTM Standard Method E 190-64. The rate of strain energy release **(Gss)** due to crack formation can be determined from the strain energy per unit cross-section.

2.5 Bend Test:

During bending, the cohesion was found to be good enough for the cracks to traverse splats, linking thermal cracks, rather than following the splat boundaries. The absence of any notable, influence of the coating particle size on the critical strain can thus be explained by the large number of thermal cracks that are generated irrespective of the powder size used. Different coating materials, however, resist thermal cracking differently. This is believed to be the main reason for the differences in critical strains.

3. RESULTS AND DISCUSSION

Below Fig.10 & Fig.11 shows FEM analysis & XRD of INCONEL-718 powder.



(a) Before Bending (b) After Bending

Fig.10 Sem Images of Inconel-718 powder

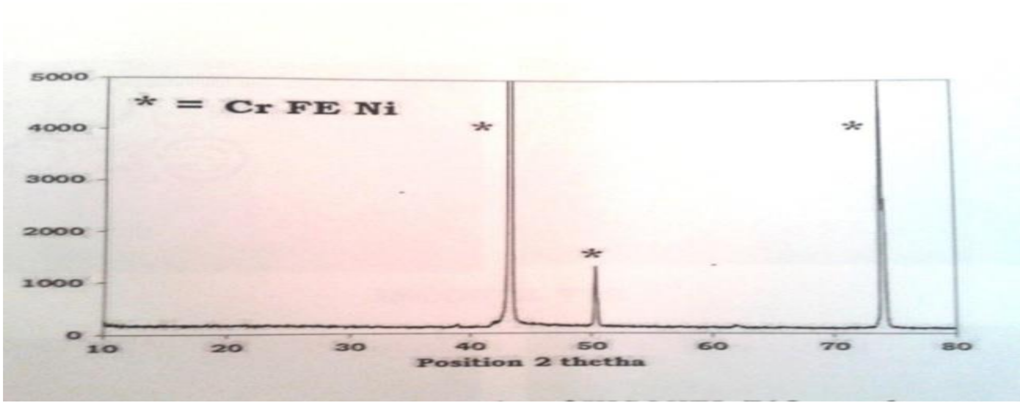


Fig.11 Showing XRD peaks of INCONEL-718

The SEM micro-photographs of the developed Inconel-718 coatings on Mild Steel Substrates are shown in Fig.10. Its confirming the presence of materials such as Ni,Co,Fe,Cr there by confirming Inconel Matrix.

With reference to Fig.11 at about 40-45, 50-53 & 70-73 angle of degrees the Cr, Fe & Ni particles present in Inconel-718 powder rises from the pattern shows maximum height value representing their presence, remaining values shows the presence of other particles of Inconel-718 powder in X-Ray Diffraction patterns.

4. RESULTS OF BENDING STRESS VALUES

Table 3.1 shows the Experimental and Table 3.2 shows the Analytical results.

Table 3.1 EXPERIMENTAL

Coating Thickness	**Load**	**Load**	**Load**
	2000 N	**3000 N**	**4000 N**
Without	287.35 Mpa	431.03 Mpa	574.71 Mpa
0.25 mm	221.34 Mpa	334.12 Mpa	445.14 Mpa
0.5 mm	173.83 Mpa	260.74 Mpa	347.66 Mpa
1 mm	116.36 Mpa	174.54 Mpa	232.72 Mpa

Table 3.2 ANALYTICAL

Coating Thickness	Load	Load	Load
	2000 N	**3000 N**	**4000 N**
Without	306.87 Mpa	448.23 Mpa	591.35 Mpa
0.25 mm	238.26 Mpa	357.05 Mpa	475.66 Mpa
0.5 mm	192.56 Mpa	288.59 Mpa	384.50 Mpa
1 mm	133.12 Mpa	199.41 Mpa	265.43 Mpa

Table3.3 STRAIN ENERGY RELEASE RATE

Coating Thickness	Load	Load	Load
	2000 N	**3000 N**	**4000 N**
Without	35.945	80.876	143.780
0.25 mm	-566.94	-1275.61	-2267.76
0.5 mm	-49.127	-110.53	-196.50
1 mm	15.50	34.87	62.00

Below Fig.12 and Fig.13 gives Crack intiation Crack intiation after bend test Bended samples.

Fig.12 Crack intiation after Bend test

Fig.13 Bended sample

As the coating thickness is increasing its Bend deflection is decreasing and if no coating means its deflection is maximum. Due to bending stress the sample get initiation of crack at the point of contact and if stresses are exceeding means the crack propagates and sample will gets failure in the form of Ductile fracture.

Below Fig.14 Shows Ansys result for 0.25mm thickness at 2000N load condition

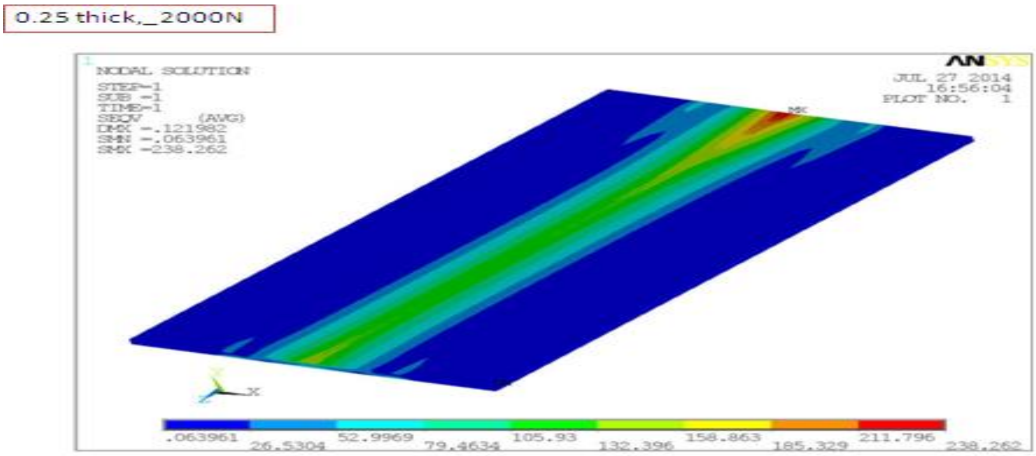


Fig.14 Von-misses stress distribution

The results of Displacement plot is shown in Fig.15

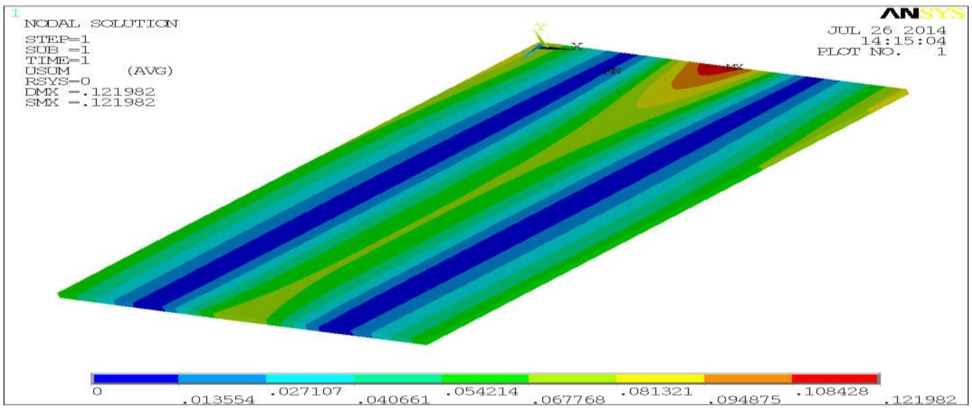


Fig.15 Displacement Plot

The results of Contour plot is shown in Fig.16

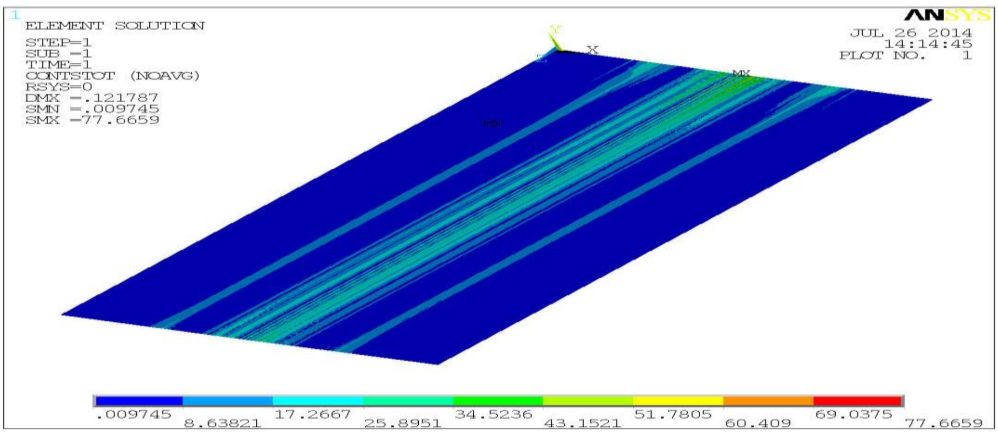


Fig.16 Contour Plot

The below plot shows Bending stress v/s Load for 0.25mm coating thickness as shown in fig.17

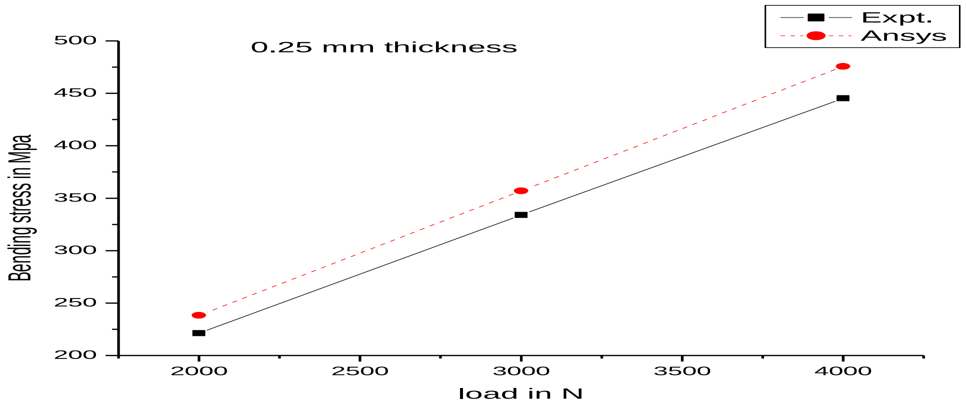


Fig.17 Graph of Bending stress v/s load for 0.25mm coating thickness

As 250 µ thickness of Inconel-718 is coated MS sample its Bending stress value increasing gradually. Experimental and Ansys values approach each other by slight variation of errors.

Below Fig.18 Shows graph of Bending stress v/s Thickness for 2000N Load.

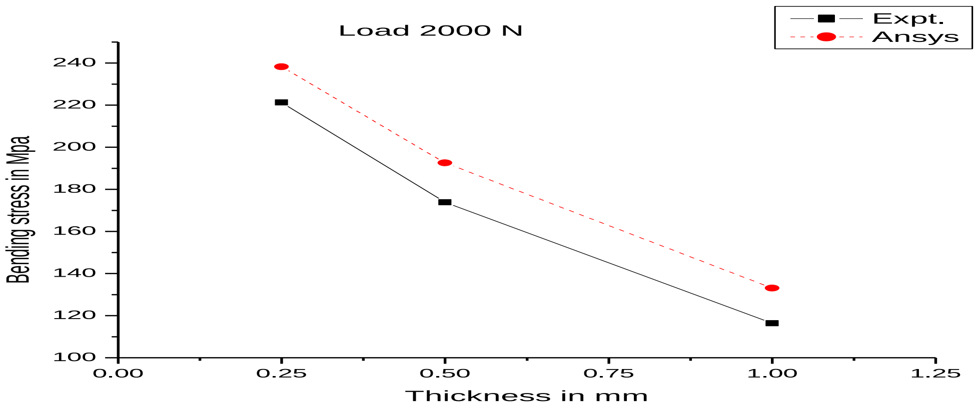


Fig.18 Graph of Bending stress v/s Thickness for 2000N load

As the Thickness is increasing means its Bending stress value is decreasing for the load of 2000 N is applied. Experimental and Ansys values approach each other by slight variation of errors.

Below Fig.19 Shows graph of Load v/s Energy release rate for 0.25mm coating thickness.

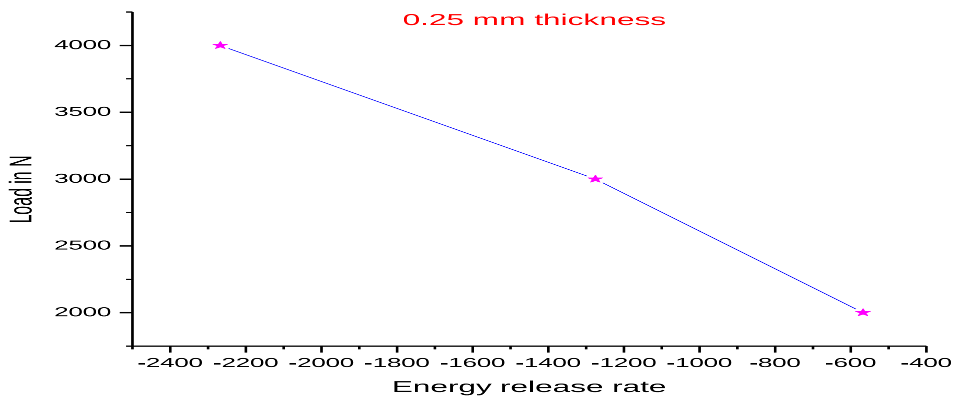


Fig.19 Load v/s Energy release rate for 0.25mm coating thickness

For 250 µ thickness of coated sample its Strain energy release rate is decreasing as its loading condition is increasing due increase of its resistance to bend or compressive load bearing capacity.

5. CONCLUSION

The following conclusions were arrived from analysis and experimental results for Bending Stresses on coating materials.

- Inconel-718 Powder has been successfully coated on Mild Steel substrate by HVOF process.
- It was found that coated samples gives less bending stress value than that of uncoated sample showing that increasing of its strength to resist to bending load.
- As the coating thickness increases its resistance to Bending increases gradually.
- As the load increases with constant thickness, its Bending stress also increasing significantly.
- As the Thickness of coating increases with constant Loading conditions, its bending stress also Decreasing significantly.
- Experimental and analytical values are matching with small variations.

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