International Journal Of Advance Research, Ideas And Innovations In Technology
IJARIIT
ISSN: 2454-132X
Impact factor: 4.295
(Volume 5, Issue 5)
Available online at: www.ijariit.com

Lean manufacturing of NI-MO powder from piston rings plasma spray coating process

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ABSTRACT

This research aims at examining the feasibility of reusing the waste plasma spray coating powder that is collected during the plasma spray coating on piston rings. This coating process is used to improve the properties, wear resistance, corrosion resistance and provide protection against high working temperature of piston rings. During coating process apart from the powder which coated on the substrate there is plenty of wastage occurs in plasma chamber. Our research mainly aims at reusing this waste powder without compromising the quality of piston ring. Resource management was the main aim of this research, as waste powder from spraying process is reused and experimentation like x-ray fluorescence analysis, twisting fatigue, exfoliation, and microstructure analysis test has to be undertaken to analyze the piston rings to check its properties.

Keyword— *Plasma spray process, Ni-Mo powder, XRF, Exfoliation, Micrograph, Piston rings*

1. INTRODUCTION

Plasma is the fourth state of matter which has high energy electron which has equivalent temperature of 10^4 K. The plasma has been utilized in many engineering applications like welding, surface coating, photolithography, hypersonic flights, and propulsion of rockets. One such application of plasma is plasma spraying process. In this process the coating material in the powder form is allowed in the stream of high energy electrons. The powder gets heated rapidly and accelerates to very high velocity. This is impacted on the substrate surface and cools rapidly to form a coating. The plasma spraying process is a quick method for surface coating. Despite having a quick process, there also occurs loss in coating powder. The major loss in this process is the undeployed coating powder. The coating powder that is wasted is mixed with water scrubber. The prime motive of this project is to re-use this wasted powder by extracting it from water scrubber. This reutilization process is beginning by identifying the source of extraction of waste powder. Here the potential source is water scrubber. Once the source is identified the powder is extracted from it and mixed with new powder. This blend is now coated on the piston rings and it is tested for strength and rigidity.

2. PLASMA SPRAYING PROCESS

Plasma spraying is a material processing technique that uses the energy of an electric arc and gases to generate a plasma beam capable of melting and depositing metallic and non-metallic materials on a substrate. This technique has been used to develop protective coatings of ceramics, alloys, and composites to enhance the surface properties of critical components operating in a severe environment. In conventional plasma spraying, an arc is created between a rod/stick type tungsten cathode and a nozzle type copper anode (both water-cooled). Plasma generating gas is forced to pass through the annular space between the electrodes. While passing through the arc, the gas undergoes dissociation and/or ionization in the high-temperature environment resulting plasma. The ionization is achieved by collision of electrons of the arc with the neutral molecules of the gas. The plasma protrudes out of the electrode encasement in the form of a jet. The material to be coated is introduced into the plasma jet in powder form in metered quantity by means of carrier gas. The powder particles, as they enter the plasma jet, are heated and melted and the molten droplets absorb the momentum of the expanding gas. As these molten droplets strike the substrate surface, they flatten and get anchored to the surface irregularities to form an adherent coating. The coating builds up layer by layer. Plasma spraying has certain unique advantages over other competing surface engineering techniques. By virtue of the high temperature and high enthalpy available in the thermal plasma jet, any powder, which melts without decomposition or sublimation, can be coated keeping the substrate temperature as low as 500°C. The coating process is fast and the thickness can go from a few tens of microns to a few mm.

3. PROBLEM STATEMENT

A problem statement is a set of statements that defines a problem to be resolved. The issue is that a large quantity of Ni-Mo powder is left as slurry. Due to this, a large quantity of new Ni-Mo powder has to be brought which adds extra cost to the production. The main objective is to reduce the wastage of powder by reusing the unused Ni-Mo powder.

4. PROBLEM ANALYSIS

Problem analysis is a set of analytic tasks involves studying the problem thoroughly with the objective to find out a clear solution for the problem. In order to have strong fundaments, it is very important to collect statistical data on deposition efficiency. By calculating the same it is possible to calculate the percentage of powder wasted during the plasma spraying process using which the value of extracting it can be evaluated. The deposition efficiency can be determined by a simple gravimetric method.

5. GRAVIMETRIC ANALYSIS

The gravimetric analysis shows the amount of a certain substance present in a composition.

Table 1: Gravimetric Analysis

Description	Before spray (g)	After spray (g)	Difference in weight(g)	Percentage (%)
Masking Cover	4,215	4,282.5	67.5	11.84
Mandrel	11,314	11,429.4	115.5	20.26
Grinding	11,646	11,429	216.5	37.98
Waste Powder			170.5	29.91

Table 1 shows the gravimetric analysis where the weight of the component before and after the coating is tabulated along with percentage change in weight. The data shows that around 30% of powder is not deposited properly on the substrate. The powder which didn't deposit on the rings may either be coated on the masking cover of the mandrel or be thrown away unmelted. The powder thrown away passes through a draught which then falls on a water scrubber. Hence water scrubber is the source from which the wasted power can be recovered successfully.

5.1 Extraction of used powder from the scrubber

Almost 30% of coating powder is not deposited on the mandrel. The powder that is not deposited is being collected in the scrubber. The scrubber is the main source of recovery of coating powder. However, cent percent recovery is not possible as there exist some losses. The powder which is not deposited passes through a draught and falls inside a water scrubber. The powder due to high specific gravity settles at the bottom and forms sludge. The sludge is kept in a tank and the powder is allowed to settle at the bottom. The powder which is deposited at the bottom is then filtered using a filter cloth wherein the powder is retained. The filtrate is roasted at 100^{o}C for 30 minutes.

5.2 Testing of used powder from the scrubber

The powder which is extracted and processed for reuse is tested and characterized. The various tests performed are Sieve analysis, X-Ray powder diffraction, Scanning electron microscope image, Chemical compositions analysis. These tests were performed under controlled conditions and the results obtained were carefully examined.

5.3 Sieve Analysis Test

Sieve analysis is a practice or procedure used to assess the particle size distribution of granular material. The size distribution is often of critical importance to the way the material performs in use. Sieves of 40 microns and 100 microns were used for sieve analysis test. Initially, total weight of the sample is measured. Powder sample is poured in 100-micron sieve and shaken in horizontal circles with intermediate tapping. The powder which passed through the 100-micron sieve is sieved in 40-micron sieve. The weight of the powder retained in each stage is measured and percentage is calculated using the following equation: Percentage retained is equal to the ratio of weight of sample powder retained to the total weight of the sample powder.

Table 2: Calculation of percentage of powder retained form the scrubber

Sieve (Microns)	Scrubber Powder (g)	Percentage (%)
100	235	10.06
40	1420	60.08
PAN	610	26.12

The above table shows the percentage of powder retained from the scrubber. Almost 60% of scrubber powder is retained in 40-micron sieve which is the highest amount followed by pan having 26% of the retained powder. From the sieve analysis report it is estimated that about 2335 grams of powder are obtained from the scrubber.

5.4 Visual inspection

Visual inspection of regular powder and used powder is done for 100, 40 microns size and the comparison figure is shown below.

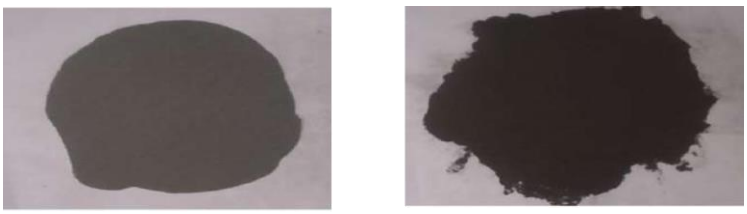

Fig 1: Pictures of regular and used molybdenum powder

From the visual inspection, it is found that regular Ni-Mo powder is light grey color whereas the color of used Ni-Mo powder is a dark grey color.

5.5 X-ray fluorescence analysis

X-ray fluorescence is the emission of characteristic "secondary" X-ray from a material that has been excited by bombarding with high-energy X-rays or gamma rays. With the help of XRF, the chemical composition of used and new Ni-Mo powder is determined and tabulated below.

Table 3: Chemical composition of regular and used powder

Element	Regular Powder	Used Powder
Nickel	56.56	67.67
Molybdenum	44.17	28.42
Iron	0.34	1.52
Titanium	0.9	0.62
Chromium	3.59	4.03
Copper	0	0.23
Manganese	0.19	0.17
Cobalt	0.2	0.15
Vanadium	0.04	0
Niobium	0.27	0.06

The comparison table shows that the used powder has more Nickel content than regular powder. It is also clear that the molybdenum content is low in used powder than that of a regular one.

5.6 Scanning Electron Microscope

A scanning electron microscope is a type of electron microscope that produces images of a sample by scanning the surface with a focused beam of electrons. The images of used and new Ni-Mo powder studied under scanning electron microscope is shown below.

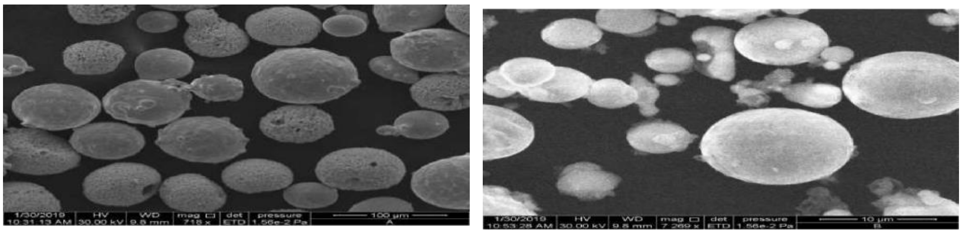

Fig 2: SEM images of regular and used powder

6. EXPERIMENT PROCESS

The used powder is collected and prepared to be mixed with the used powder for plasma spraying. 5 trials of the spraying process are done on the ZQKC4108 steel rings assembled in a mandrel of 130 mm using a plasma spraying technique. Each trial contains varying mixtures of regular powder and used powder to test the various characteristics of the coating:

1. Trial1: 100% regular powder
2. Trial 2: 10% used powder + 90% regular powder
3. Trial 3: 20% used powder + 80% regular powder
4. Trial 4: 30% used powder + 70% regular powder
5. Trial 5: 40% used powder + 60% regular powder

6.1 Testing of piston rings:

The piston rings coated using the blend powders are tested for various characteristics and properties. The tests include the Exfoliation test, Microhardness test, Microstructure analysis, Porosity, Twist fatigue test.

6.2 Exfoliation test

Exfoliation is the process of removal or chipping up of the sprayed coatings on the piston rings. This test is conducted to check the bonding strength of coatings that is how strongly the powder particles are bound to the substrate material. This test is done using a tensometer. It is a device used to evaluate the tensile properties of materials such as their Young's modulus and tensile strength.

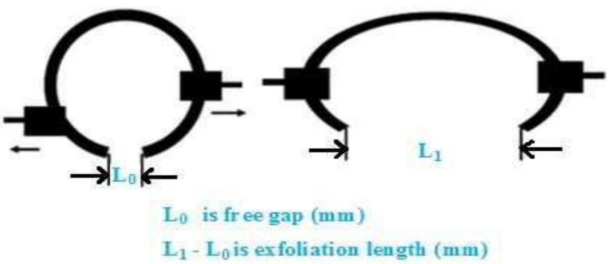

Fig 3: Stretching of a piston ring in exfoliation test

The test is carried out by clamping the free ends of piston rings on fixed and movable jaw. Now the free end clamped to movable jaw is stretched apart till the ring comes out of the clamp. Thus, the maximum stretches up to which bond remains intact without peeling off is measured.

Table 4: Exfoliation test results of ZQKC4108 steel rings

Description	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5
Free Gap (mm)	10	10	10	10	10
Specification (mm)	55	55	55	55	55
Maximum Stretch (mm)	160	140	155	130	155
Remarks	No chip off	No chip off	No chip off	No chip off	No chip off

The table shows the exfoliation test conducted on the piston rings. For various trials there is no failure of piston rings, in other words, there is no chip off.

6.3 Twisting fatigue test

The twisting fatigue test is done to determine the resistance offered by the piston rings to twisting. It tells that how long will the piston ring withstand the twisting load and also evaluates the bond strength of the rings. The stroke length for the twist fatigue test can be determined as follows:

Stroke length= 0.8 X piston ring diameter= 97 x 0.8= 77.6 mm

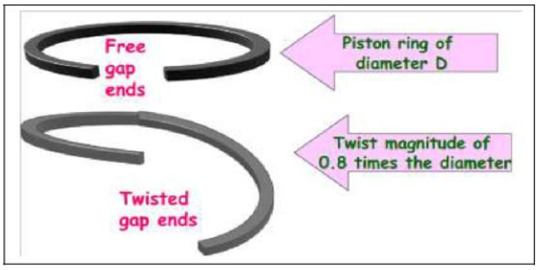

Fig 4: Twisting of piston ring

The testing is carried out by clamping the piston rings to the fixed and movable jaws of the universal testing machine. Now, load, frequency of operation and the number of cycles to be applied on the movable jaw are fed into the computer which is connected with the UTM. Thus, the maximum stretch up to which bond remains intact without peeling off is measured.

Table 5: Twist fatigue test results of ZQKC 4108 steel rings

Description	Trial 1	Trial 2	Trial 3	Trial 4	Trial 5
Number of cycles completed	10,000	10,000	10,000	10,000	10,000
Peel Off	NO	NO	NO	NO	NO
Ring Broken	NO	NO	NO	NO	NO

The standard specification is 8000 cycles and it is found that the coatings on the rings don't peel off for more than 15000 cycles which ensures that they possess adequate bond strength.

6.4 Microhardness test

Microhardness is the hardness of a material gauged with instruments using small indenters. Microhardness testing is a method of determining a material's hardness or resistance to penetration when test samples are very small or thin, or when small regions in a composite sample or plating are to be measured. The hardness of piston rings is determined by Vickers hardness test. The test is performed by applying controlled pressure for a standard length of time with a square-based diamond pyramid indenter. A load of 3N is applied on the piston rings and the average hardness is obtained.

Table 6: Micro hardness test results of ZQKC4108 steel rings

Trial	Average Hardness
1	336.23
2	318.2
3	314.72
4	305
5	295.98

The hardness specified for the piston ring must be greater than 200. From the testing, it can be concluded that all the trials have met the hardness specification.

6.5 Microstructure Analysis Test

The microstructure analysis is carried out to determine the grain size, thickness of surface coatings and surface or internal flaws. The microstructure of the given sample is analyzed under metallurgical microscope. The analysis is carried out to check the depth of the coating that is deposited on the piston rings

Table 7: Measurement of depth of coating on the piston rings

Description	Coating Depth (D) Specification: 0.230 mm
Trial 1	0.311
Trial 2	0.271
Trial 3	0.28
Trial 4	0.261
Trial 5	0.269

The table shows the coating depth in different trials. Trial 1 has the maximum coating depth followed by trial 3. It is clear that all the trials have met the specifications

7. MICROGRAPH

The carefully prepared specimen is placed on the mounting stage of the metallurgical microscope. The 10x objective lens is oriented so as to get 100x, 500x total magnification. The microscope is interfaced with a computer loaded with "Axiovision SE64" image analysis software. The microstructure is now visible in the software which can be used for further analysis. The microstructure images (otherwise called as micrographs) obtained are shown below.

Fig. 5: Microscopic image of Trial 1 sample

The microscopic analyses of 100 % Ni-Mo powder are shown above. It reveals that the powder has a porosity of 2.17%.

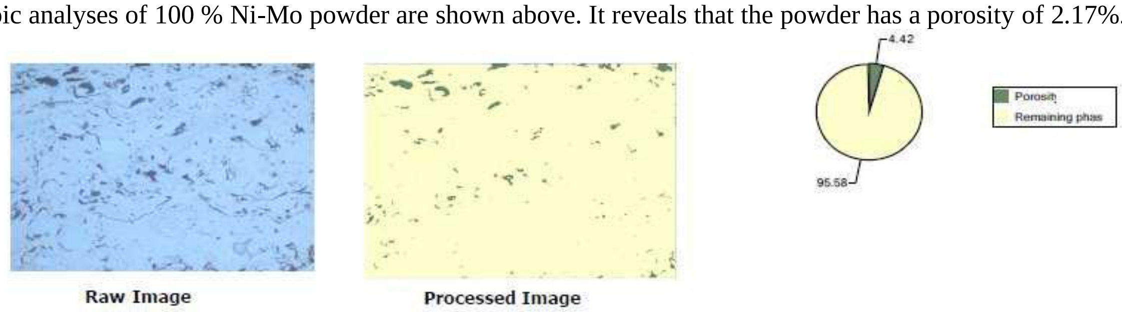

Fig. 6: Microscopic image of Trial 2 sample

The microscopic analysis of 10% used and 90% Ni-Mo powder is displayed above. It shows that porosity of the sample is 4.42%.

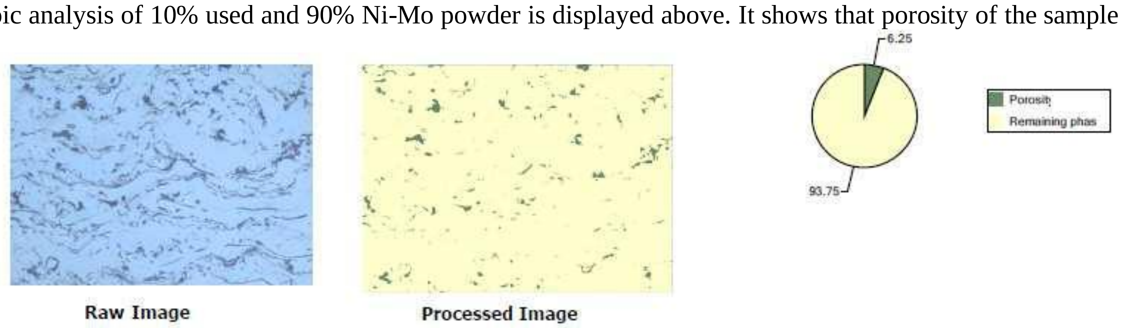

Fig. 7: Microscopic image of Trial 3 sample

The microscopic study of the 20% used and 80% new powder is given above. It shows the porosity value of 6.25%.

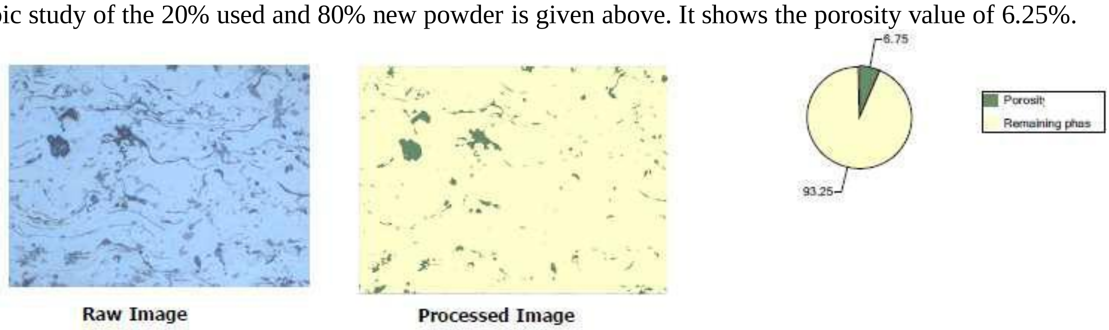

Fig. 8: Microscopic image of Trial 4 sample

The micrograph of 70% of regular powder is provided above. It is clear that the porosity of this blend is 6.75%.

Fig. 9: Microscopic image of Trial 5 sample

The micrograph of 60% of regular powder is displayed above. It can be seen that porosity of this sample is 7.8%. From the microscopic analysis it is concluded that the porosity of the powder increases with the increase in concentration of used powder.

8. CONCLUSION

The feasibility of reuse of waste Ni-Mo powder has been checked and it is found to be viable. It is evident from the above work that a blend containing 10%,20%,30%,40% waste powder and 90%,80%,70%,60% regular can be coated successfully on the piston rings using the same piston rings using the plasma spraying machine without changing any of the operating parameters of the machine. The results of the various experiments prove that piston rings coated using this blend powder fulfill all technical and functional expectations and meet the industry specifications. Strictly no compromise has been made with the quality of the product and hence this 10% blend powder can be used as common as the regular powder. 20% of regular powder can also be reuse by analysis of powder since it does not meet the specification only in the porosity test. As a consequence of using this blend powder, it is possible to reduce the net waste powder produced during plasma spraying. In addition to this, the waste powder which had only scrap value will take roughly 10 times higher value. Hence the coating cost per ring is reduced eventually and increases the profitability.

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