A study of thermal spray coated surface with nano composite powder of CNT+WC14C0

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Abstract. Coatings obtained from thermal spray process are being developed for wide varieties of applications in aerospace and automotive industries. To enhance the wear resistance in the YAWING in wind mills, a new study is required to find out and analyze the surface properties of the surface of Yawing. In this study to enhance the surface properties, a new nano composite powder has been developed and coated on SS304. To synthesis of CNT+WC14Co, initially a binder material of 0.5% Poly Vinyl alcohol solution was prepared and made use as a binder between CNT and WC14Co particles. The synthesized nano composite powder is coated over SS304 samples as per Taguchi design of experiments by Detonation gun coating technique. The coated samples are undergone the tests of micro hardness and Surface roughness. It was found that a significant improvement in micro hardness and there is no significant improvement in surface finish. The best combination of input parameters is obtained through Taguchi method and untried combination’s results also have been predicted through Taguchi method. Response surface methodology (RSM) is used to develop a mathematical model.

1. Introduction
Surface engineering plays a major role in altering the wear resistance and degradation of the metal surfaces. It has vast applications in various fields of science and technology. Different kinds of techniques utilized for the surface treatment of coatings based on the functional requirements. Among all the treatments, Thermal sprayed coatings considered as significant coatings. Thermal spray coating technology is having wide applications in varieties of engineering components like jet engine to Prevent high temperature oxidation, agricultural components to enhancing the wear resistance, electrical components to enhance conductivity or enhance insulation property etc. Though several varieties of thermal spray coating technique, plasma spraying, electric or wire arc spraying, flame spraying, high velocity oxy-fuel coating spraying (HVOF), Detonation Gun Coating are having more application in engineering field.
The discovery of Carbon nano tubes is considered as a revolution in the nanotechnology which
comprises of carbon atoms linked in hexagonal structures. The flexible properties like high tensile strength, elastic nature, high thermal conductivity and electric conductivity of these structures enabled their usage in various fields of science.

2. Literature review
Rodriguez [1] has conducted experiments on various coating samples. He observed that for the coatings that are reinforced with MWCNT using thermal spraying technique has an abrasive wear resistance, which is almost five times higher than the normal metals. Qian-Gang Fu [2] recorded the characteristics of toughness, bonding strength and thermal shock resistance of the carbon nanotube reinforced Si-C coating for ultra high temperature ceramics. It has been concluded that the reinforcement of CNTs elevated the properties of toughness, hardness, bonding strength and thermal shock resistance. Arabani [3] studied the rheological and thermal sensitivity of asphalt binders like carbon nanofibres (CNFs). These studies helped in concluding that CNTs reinforced coatings can also be used as binders in HMA as they have significant improved performance against rutting, thermal and fatigue cracking. Barberio [4] analysed the metal nanoparticles deposited on the carbon nanotube substrates, which produced by laser ablation method. Integration of the MNP / CN results in the formation of product, which has combined advantages of unique electrical, optical, magnetic and catalytic properties. The SEM images showed nano particles like Ti, Co and Ni formed a continuous layer has a large uniformity and thickness. Xibeo Pei [5] conducted studies on fabrication process of Ceramic containing MMC coatings by thermal spraying having potential applications in thermal systems like heating and cooling systems, power generation and energy storage. It is concluded that thermal spray technique provides a uniform adhesion and distribution of spray particles over the substrate.

Enrique Samaniego [6] conducted experiments on the fabrication methods of MWCNTs using various coatings. The backscattered electron images showed an increase in the cross section area which helped in concluding the increase of thickness of coating.

Balan et al [7, 8 and 9] performed detonation gun coating for predicting and optimizing the various process parameters.

Valarmathith et al [10, 11 and 12] studied the effect of thrust force in drilling of composite material using RSM techniques.

3. Experimental work
Literature review suggests that thermal spray process is a best method of coating over metal surfaces for achieving higher wear resistance, corrosion resistance, hardened surface and good surface finish. In this present work thermal spray of WC14CO+CNT over stainless steel is done and various properties are analyzed.

3.1. Experimental setup
An assembly of detonation gun (Figure 1) consisting of a barrel which will be used to mix the oxygen and acetylene along with the powder to be coated and spray the semi molten powder over the substrate to be coated by means of detonation. Required thickness of coating can obtain by using multiple layers of coatings. For synthesizing coating powder (WC-14Co+CNT), a suitable method was identified after several iterations. Polyvinyl alcohol (PVA) is used as the binding agent. To prepare 0.5% of PVA, 5 g of PVA crystals mixed in 100 cc of water, and then the mixture has been allowed to stand (Figure 2). After 24 hours, PVA became a thick gel-like substance on water. For final synthesis, 7 cc of PVA (0.5% PVA) added to 10 cc of WC-14Co+CNT and the coating powder is synthesized by standard procedure (Figure 3). Here, a sonicator is used for mixing PVA and WC-14Co+CNT. A sonicator generates ultrasonic waves that allow mixture to vibrate and mix properly. Sonication process has been performed for nearly 120 minutes for complete mixing (Figure 4).
Figure 1. Detonation gun process

Figure 2. PVA preparation

Figure 3. Preparation of WC14Co+CNT
After the ultrasonication, the liquid mixture was heated in a hot air oven at a temperature of 85-90°C for nearly 120 minutes accompanied with a continuous stirring with the help of stirrer rod. Finally, a free flowing powder of WC-14Co+CNT obtained. The coating varies with different quantities with different thickness and flow rate of powder. Different samples (Figure 5) made by spraying different compositions of coating powders.

The above samples tested to observe the improvement of wear property by conducting micro hardness test, surface roughness test and wear test using Vickers indentation machine and profilometer. A profilograph recorded in profilometer for measuring the surface roughness uses oscillations from the stylus. It is converted optically or electrically into signals, which are recorded on a photosensitive film or paper.

4. Results and discussion

4.1. Factor effect of single coating powder on micro hardness

Nine experiments have been carried out and the responses were recorded to find the optimal combination of input parameters to enhance the hardness of the surface. Macro hardness sample
descriptions are presented in table 1, 2 and 3.

| Table 1. Micro hardness sample description of 1 % CNT + WC14Co. |
|-----------------|------------------|
| Sample ID | Hardness in HV 100gm |
| 1 | 1023, 1027, 1041 |
| 2 | 1011, 1033, 1023 |
| 3 | 1046, 1021, 1009 |

| Table 2. Micro hardness sample description of 1.5 % CNT + WC14Co. |
|-----------------|------------------|
| Sample ID | Hardness in HV 100gm |
| 1 | 1091, 1065, 1051 |
| 2 | 1083, 1097, 1073 |
| 3 | 1065, 1083, 1071 |

| Table 3. Micro hardness sample description of 2 % CNT + WC14Co. |
|-----------------|------------------|
| Sample ID | Hardness in HV 100gm |
| 1 | 1123, 1149, 1123 |
| 2 | 1155, 1129, 1137 |
| 3 | 1163, 1141, 1130 |

For maximizing the accuracy of the hardness values, Taguchi’s method is implemented considering the three different parameters like percentage of CNT, thickness, powder flow rate. Calculated values of \( \eta \) are presented in table 4.

| Table 4. Calculated values of \( \eta \). |
|-----------------|------------------|
| S.NO | CNT % | Thickness | Powder flow rate | A | B | C | Average | Y | D |
| 1 | 1 % | 100 | 1000 | 1023 | 1027 | 1041 | 1030.33 | 60.25 |
| 2 | 1 % | 125 | 1200 | 1011 | 1033 | 1023 | 1022.33 | 60.19 |
| 3 | 1 % | 150 | 1500 | 1046 | 1021 | 1009 | 1025.33 | 60.21 |
| 4 | 1.5% | 100 | 1000 | 1091 | 1065 | 1051 | 1069.00 | 60.57 |
| 5 | 1.5% | 125 | 1200 | 1083 | 1097 | 1073 | 1084.33 | 60.70 |
| 6 | 1.5% | 150 | 1500 | 1065 | 1083 | 1071 | 1073.00 | 60.61 |
| 7 | 2 % | 100 | 1000 | 1123 | 1149 | 1123 | 1131.66 | 61.07 |
| 8 | 2 % | 125 | 1200 | 1155 | 1129 | 1137 | 1140.33 | 61.14 |
| 9 | 2 % | 150 | 1500 | 1163 | 1141 | 1130 | 1144.66 | 61.17 |

The objective function (\( \eta \)) for Taguchi larger -the-better model used has been given in equation (1) as follows

\[
D = -10 \log_{10} (1/y^2)
\]

By using the above formula the corrected hardness is derived which is used in plotting the above
The following observations are concluded from the above graph. CNT % of coating has the largest effect on micro hardness. The surface roughness values obtained from the profilograph also support the addition of the CNT for the improvement of the micro hardness.

**Figure 6.** Factors effecting micro hardness

### 4.2. Response surface methodology (RSM)

Response surface methodology is a statistical and mathematical technique [10 and 11]. It is used to analyze the problems, in which one or more responses are influenced by many factors and to find out the quantitative relationship between the output and the input variables. This method has been initially used for model fitting of physical experiments but later it is used for the design of experiments in process optimization. It is the process of approximating a response function, based on statistical analysis of data which has been obtained at various design points.

The relationship between the control parameters and the responses is given in Equation (2) as

$$Y = f(X_1, X_2, \ldots, X_k) + \epsilon$$

(2)

The RSM model (quadratic) is established and given in equation (3) to obtain the relation between the response variable and input parameters. The model summary is presented in table 5.

$$y = +861.22565-2.13325*(\text{CNT%})+0.43745*(T)+0.15922*(\text{PFR})+32.27111*(\text{CNT%})^2$$
$$-1.79556E-003*(T)^2-7.28481E-005*(\text{PFR})^2+6.80000E-003*(\text{CNT%})*(T)$$
$$+0.012603*(\text{CNT%})*(\text{PFR})+7.41228E-005*(T)*(\text{PFR})$$

(3)

**Table. 5 Summary of the model**

| Source    | Standard deviation | R-squared  | Adjusted R-squared | Predicted R-Squared | Press |
|-----------|--------------------|-----------|--------------------|---------------------|-------|
| Quadratic | 5.0633             | 99.23%    | 98.82%             | 98.12%              | 1064.84 |
Normal probability plot is presented in figure 7. From the figure it is seen that all the points are almost close to the straight line and hence the model is effective.

![Figure 7. Normal probability plot](image)

The surface plots obtained using RSM is presented in figure 8. These plots can help to visualize the response surface and shows how micro hardness relates to two factors by keeping the third variable is kept as constant. Figure shows the relation between CNT %, thickness of coating and power flow rate. This plot indicates that the increase in CNT shows good results. Hence the more influencing factor among the three is CNT%.

![Figure 8. RSM surface plots](image)

5. Conclusions
The effects of various input parameters such a combination of different types of coating powders, powder flow rate, coating thickness on micro hardness and surface finish in coating process are evaluated in the present process. The different parameters and their influence on the responses have been analyzed through Taguchi’s method. The optimal combination of input parameters to achieve higher micro hardness has been obtained. The results of the untried combinations are also predicted. A mathematical model is developed using RSM technique to evaluate the relation between the input and output parameters.
6. References
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