APPLICATION OF TAGUCHI METHOD FOR OPTIMIZATION OF ABRASIVE WEAR CHARACTERISTICS OF TUNGSTEN CARBIDE-COBALT AND NICKEL-CHROMIUM BASED COATING ON HIGH SPEED STEEL DEPOSITED BY DETONATION GUN PROCESS

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ABSTRACT
Abrasive wear is a vital property which plays key role in the life and working of a material. In modern age of industrial development, it becomes essential to study the amount of wear a component suffers during operation at varying conditions. This paper is based on the abrasive wear characteristics of High speed steel (HSS) which has coating of Tungsten Carbide-Cobalt (WC-Co) and Nickel-Chromium (NiCr), deposited by detonation gun process. Coating has an effect on the abrasion wear behaviour of the material. The present work describes the effect of WC-Co and NiCr based coating on the HSS specimen at varying condition of loading (normal load), velocity and composition of the coating. Then the systemic properties are optimized through the Taguchi method of optimization.

KEYWORDS: *Abrasive Wear, Thermal Spraying, Coating, Detonation Gun Process, Taguchi Method.*

I. INTRODUCTION

High speed steel (HSS) is a subset of tool steels, typically utilized as cutting tools and tool bits. The life of high-speed steel can be protracted by coating the tool. A coating provides the cleanly passage to the cutting edge of a tool through the material without having material nerve to it. It helps to reduce the temperature associated with the cutting process and expand the tool life. Thermal spraying is an effective and inexpensive mode to apply thick coatings to advance surface properties of the component. Coating materials available for thermal spraying are fed in wire or powder form, heated to a molten or semi molten state and moved towards substrates in the form of micrometer-size particles. Electrical arc discharge or combustion is normally used as the source of energy for thermal spraying. Among the commercially available methods, High Velocity Oxy Fuel (HVOF) and Detonation Spray (DS) are the prominent thermal spray coating techniques to get hard, dense and wear resistant coatings as desired [1]. In this work, detonation gun spray is used for coating to enhance the properties of surface of substrate.
The present study aim at the studying the wear behaviour of high speed steel coating of Tungsten Carbide-Cobalt (WC-Co) and Nickel-Chromium (NiCr) [5-11] at various levels of normal load and speed applied on the testing machine using Taguchi method [12] [13]. Moreover, the analysis of variance (ANOVA) [14] is done to identify the most significant control factor and their interactions. This paper is organized as follows: Section II provides the details of experiments executed in the current study. Section III describes the test apparatus used. In Section IV design of experiment is expressed. Section V gives results and a discussion. Conclusion and future work has been presented in Section VI and VII respectively.

II. EXPERIMENTAL DETAILS

2.1. Material Combination Used

In this study, High speed steel is used as the substrate material and commercially available metalizing powders namely WC-Co and NiCr are used for the purpose of coating whose chemical composition is given in Table 1.

Table 1. Chemical composition (wt. %) of the substrate and metalizing powders used

S. No.	Elements	Substrate (H.S.S)	WC-Co	NiCr
1.	C	0.75	5-6	9.5-11.5
2.	v	1	-	-
3.	Si	-	-	-
4.	Mn	-	-	-
5.	Ni	-	-	14-16
6.	Cr	4	3-5	Balance
7.	Mo	-	-	-
8.	W	18	Balance	-
9.	Co	-	8.5-11	-
10.	Fe	Balance	Max 0.3	Max 0.5

2.2. Detonation Gun Spraying

D-gun spray process [3] is an effective thermal spraying technique which provides coating surface with extremely good adhesive strength, low porosity and compressible residual stresses. A precisely measured mixture of oxygen and acetylene is fed through a tubular barrel closed at one end. To prevent the possible back firing, nitrogen gas is used to cover the gas inlets. Simultaneously, a fixed quantity of the coating powder is fed into the combustion chamber. A simple spark plug is used to ignite the gas mixture inside the chamber. The combustion of the gas mixture engenders high pressure shock waves known as *detonation waves*, which then propagate through the gas stream [2]. The temperature of the hot gas stream can go up to 4000^0C and the velocity of the shock wave can reach 3500m/sec (11500ft/sec), depends on the ratio of the combustion gases. The combustible hot gases travel the barrel at a high velocity and during the process, heat the powder particles to a plasticizing stage and also accelerate the particles to a velocity typically about 1200m/sec (3900ft/sec). These hot powder particles then come out from the barrel and impact on the substrate to form a coating. The high kinetic energy of particles results the layer of dense and strong coating on the substrate [4]. The coating thickness developed on the component per shot depends on the various factors i.e. ratio of combustion gases, carrier gas flow rate, powder particle size, frequency of shots and distance between the barrel end and the substrate. Detonation spraying cycle can be repeated at the rate of 1 to 10 shots/second, depends on the type of coating material and as per the requirement of coating thickness. The chamber is indeterminately flushed with nitrogen again to abstract all the remaining hot powder particles from the chamber otherwise these can detonate the explosive mixture eccentrically and render the entire process uncontrollable. The procedure is reiterated at a particular frequency until the required thickness of coating is deposited [1].

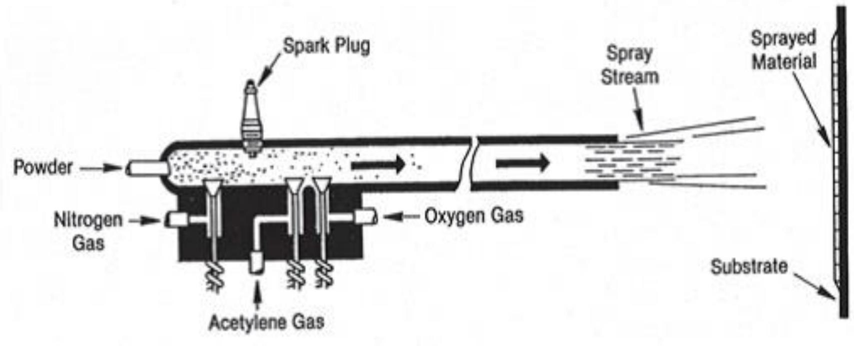

Figure 1. Schematic of Detonation Gun Process

A major attribute of this technique is the ability to apply coatings with very high melting points to substrates (work piece or part) without significantly heating the substrate. Thus coatings can be applied to fully heat treated, completely machined parts without changing the metallurgical properties the part and without the risk of thermal distortion inherent in high temperature coating processes.

2.3. Development of Coating

Prior to the coating, the high speed steel plates of dimensions 75mm x 25mm x 5mm were cleaned with acetone and grit blasted at a pressure of 3 kg/m^3 using aluminium oxide of grits size 30 grade on the 75mm x 25mm coating face, and again cleaned and dried. The standoff distance in shot blasting was kept between 120 mm-170 mm.
The grit blasted substrate was held appropriately in a fixture and the coating deposition was carried out within the samples in the stationary condition with gun traversing to and fro to obtain the desired coating thickness. The spraying conditions adopted for the coatings are given in Table 2.

Table2. Spraying condition adopted for Detonation spray process

S. No.	Parameters	WC-Co	NiCr
1.	O_2 flow rate (SLPH)	2960	2800
2.	C_2H_2 flow rate (SLPH)	2400	2240
3.	Carrier gas (Nitrogen) flow rate (m^3/h)	1040	1040
4.	Spray distance (mm)	165	165
5.	Frequency of shots (shots/sec.)	3	3

2.4. Coating Samples

Three sets of samples were prepared as per the requirement of the experimental plan and are shown in Table 3.

Table3. Different sets of samples

S. No.	Set	Samples
1.	Set I	High speed steel (HSS)
2.	Set II	Tungsten Carbide-Cobalt (WC-Co) as sprayed
3.	Set III	Nickel-Chromium (NiCr) as sprayed

WC-Co and NiCr coated samples were taken in the as sprayed conditions and are shown in the Figure 2.

Coated sample of WC-Co Coated sample of NiCr

Figure 2. Set of Coated samples

2.5. Coating Thickness Measurement

The thickness of the coatings was monitored during the detonation gun spraying with a microprocessor coating thickness gauge Mini Test-600B. Efforts were made to obtain coating of uniform thickness. Uniform thickness coatings of 250µm ±50µm of WC-Co and NiCr powders were deposited on the substrate material.

III. TEST APPARATUS

Dry Sand Rubber/Wheel Abrasion Test (ASTM G 65)

Dry sand rubber/wheel abrasion test is widely used abrasion testing method [15]. The testing method is utilized to determine the resistance of materials to low load sand abrasion.

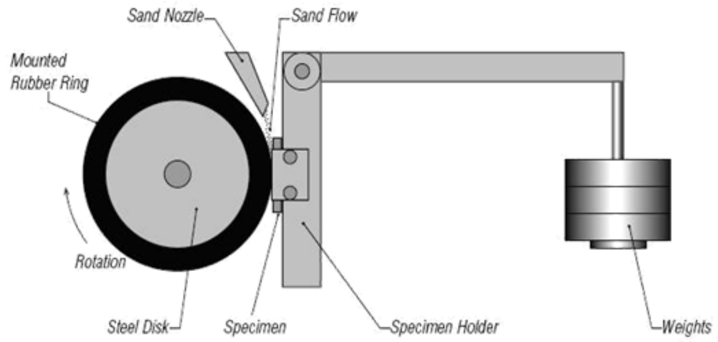

Figure 3. Dry Sand Rubber/Wheel Abrasion Test

In this study, the abrasion tests were done using a three–body solid particle rubber wheel test rig using silica grits as the abrasive medium. The coated samples of 75 mm × 25 mm × 6 mm dimensions were tested using dry sand rubber wheel abrasion tester. The coated samples were mounted rigidly in the sample's holder and were permitted to press against the rubber wheel' rim with the desired normal force by applying a known dead weight through a lever arrangement. After that the dry silica sand was allowed to fall freely between the rubber wheel and the coated surface while the wheel was rubbing against the coated surface. The coated samples were ultrasonically cleaned with acetone, dried and weighed using an electronic weighing balance with an accuracy of 0.1 mg. The samples were subjected to abrasion for 200 revolutions, cleaned and weighed and the weight loss was resolved. The above strategy was repeated till the weight loss for 200 revolutions reached a constant value from the high initial values. The mass loss obtained was normalized with the coating density to obtain the volume wear loss. The coating density values were assessed by the coating weight gain method in which the mass of the coating deposited was normalized with the volume coating. The coating density values obtained ranged from 3.8 g/cm^3 to 4.4 g/cm^3 for WC-Co and 3.2 kg/m^3 to 4.2 g/cm^3 for NiCr coating. The coating density values taken for WC-Co coating were 4.4 g/cm^3 and for Ni-Cr based coatings were 4.2 g/cm^3.

IV. DESIGN OF EXPERIMENT

Design of experiment (DOE) [12] is a significant analysis tool for modeling and analyzing the influence of control factors on the performance output. The most vital phase in the design of experiment lies in the selection of the control factors. In Table 4 the operating conditions are given under which the erosion tests are carried out. The tests are conducted at room temperature as per experimental design given in Table 5.

Table 4. Operating conditions

Control factors	Level		
	I	II	III
Composition	High speed steel	Tungsten Carbide-Cobalt (WC-Co)	Nickel-Chromium (NiCr)
Velocity of wheel	1.729 (m/sec), 100 rpm	1.9832 (m/sec), 150rpm	2.3542 (m/sec), 200 rpm
Normal loading	4.905N, 500gm	9.81N, 1000gm	19.62N, 2000gm

Taguchi method is used to optimize the design of experiment based on the number of control factors and number of levels [13]. The control factors viz composition, sliding velocity and normal load, each at three level, are considered in this study as per L_9 (3^3) orthogonal array design. Three parameters each at three levels would require 3^3 = 27 in a full factorial analysis. Whereas, Taguchi factional methodology decreases to 9 runs just advertising an incredible point of preference.

The experimental observations are changed into a signal-to-noise (S/N) ratio. There are various S/N ratios which depend on the type of characteristics. The S/N ratio for the minimum erosion rate comes under *lower-the-better* (LB) quality characteristic, which can be figured as the logarithm's transformation of the function is given by:

S/N Ratio, $\eta = -10 \log 1/n (\Sigma y^2)$……………………………………… (1)

Where,

n = number of repetitions or observations,

y = observed data.

Table 5. Experimental design using L_9 orthogonal array

S. No.	Composition	Velocity (rpm)	Normal Load (gm)	Specific wear rate (mm^3/Nm)	S/N ratio (dB)
1.	HSS	100	500	0.00565	44.9500
2.	HSS	150	1000	0.00542	44.1344
3.	HSS	200	2000	0.00398	45.8951
4.	WC-Co	100	1000	0.00095	47.0938
5.	WC-Co	150	2000	0.00052	48.0475
6.	WC-Co	200	500	0.00036	48.8319
7.	NiCr	100	2000	0.02160	41.0864
8.	NiCr	150	1000	0.01016	40.9131
9.	NiCr	200	500	0.00305	41.3627

V. RESULT AND DISCUSSION

From the table of design of experiment the overall mean of the wear rate is found. Figure 4 graphically indicates the response of three control factors on wear rate and Figure 5 shows the overall variation of the specific wear rate with velocity and Figure 6 shows the variation of specific wear rate with normal load for various compositions. The analysis for the S/N ratio is done by utilizing the MINITAB14 software which is especially designed for experimental design applications.

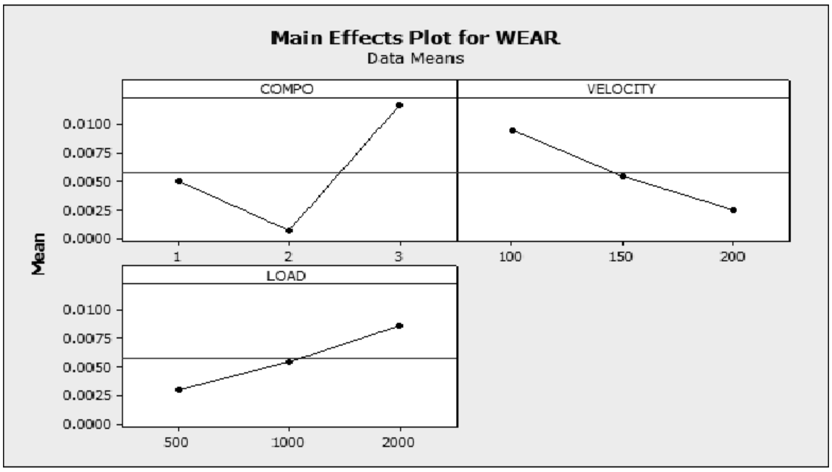

Figure 4. Effect of control factors on wear rate

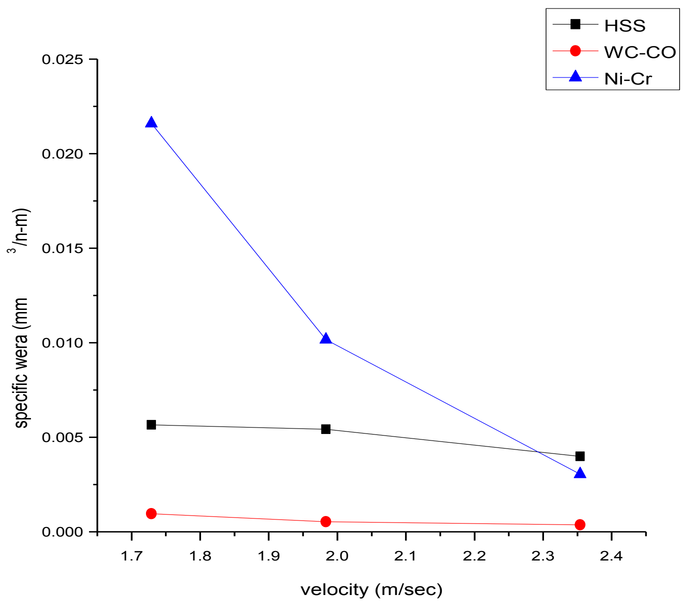

Figure 5. Effect of speed on specific wear rate for various compositions

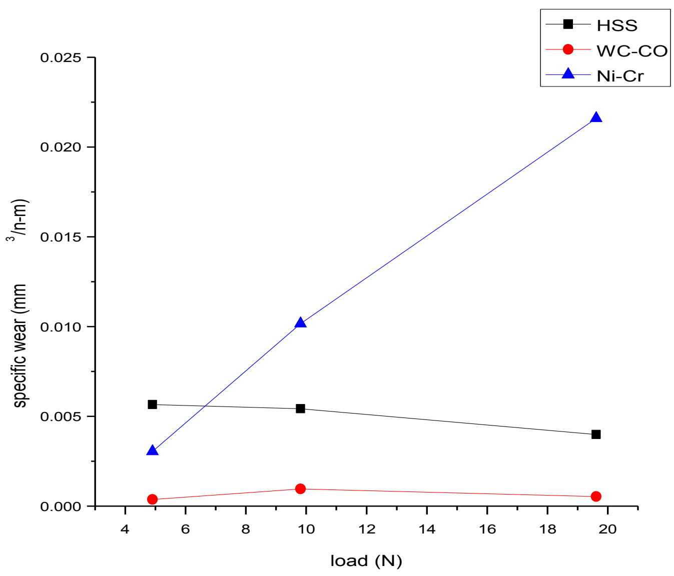

Figure 6. Effect of normal load on specific wear rate for various compositions

Analysis of the result leads to the conclusion that composition plays the major role in the wear rate analysis followed by velocity and then normal load as is evident front the Table 6 below.

Table 6. Response Table for Signal to Noise Ratio

Level	Composition (A)	Speed (B)	Load (C)
I	45.3265	44.376	45.04
II	47.991	44.698	44.3804
III	41.1207	45.363	45.009
Delta	6.8703	0.987	0.6596
Rank	1	2	3

Factor A represents the composition of the system, Factor B represents the velocity of the testing condition and Factor C represents the normal load for the experimentation.

Analysis of Variance (ANOVA)

The purpose of the analysis of variance (ANOVA) is to find out the order of factors affecting the quality characteristic [14]. Table 7 shows the result of the ANOVA for the wear rate.

Table 7. ANOVA Table

Factor	**DOF**	Sum of Square **S**	Variance **V**	Variance Ratio **F**	Pure Sum **S'**	Percentage Contribution **P (%)**
A	2	$1.835087*10^{-4}$	$9.175435*10^{-5}$	3.115614	$1.246091*10^{-4}$	34.5678
B	2	$6.939567*10^{-5}$	$3.469783*10^{-5}$	1.17820	$1.0495973*10^{-5}$	2.9116
C	2	$4.867262*10^{-5}$	$2.433638*10^{-5}$	0.82636	$1.022707*10^{-5}$	2.83709

Hence highest contribution is for composition and then velocity and least contribution for normal load as is evident from their % contribution values.

VI. CONCLUSION

The presented paper basically works on the abrasion wear property of high speed steel and the various coatings applied on it. Factors like normal loading, coating constituent and velocity are seen to play role for the maximization of wear rate. To optimize the objective, mathematical model is developed and the contribution of various factors on the wear rate is established. Hence, in accordance with material the following conclusions are listed:

a) Wear in the high speed steel is decreased by the use of coatings.
b) Coatings have high adhesion to the high speed steel specimen.
c) Composition of the coating plays the most vital role for the least wear in the specimen.
d) WC-Co has the least wear rate for optimized condition.
e) Optimized loading condition is 9.81N or 1000 gm at the velocity of 1.729 m/sec or 100rpm for WC-Co based coating on high speed steel.

VII. FUTURE WORK

The method presented in the paper can be utilized for the other engineering materials. Taguchi approach can be used for multi-factor optimization of the problem and to reduce the error.

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