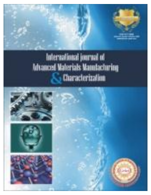

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Optimization of Abrasive wear Characteristics of Tungsten Carbide and Chromium Carbide based coating on Mild Steel deposited by Detonation Gun Process using Taguchi Method

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A B S T R A C T

Mild steel forms the basis of almost every industry, the present industrial system survives on the soul of some of the basic elements and their systematic properties like strength, toughness, hardness, failure stress etc. Along with these major properties some properties are such they may seem to be less important and not considered but for the long run they play major part in the life and working of material. One such property is the abrasive wear property of the material. Though the abrasion in one run of the system looks very negligible and not considerate but when the mechanism of abrasion is taken into consideration on the large machinery like the turbines and turbo propellers this becomes very important and its consideration forms the major study part. The present study generally works on the abrasion wear often called as a three body wear system on mild steel and the coating of tungsten carbide and chromium carbide on it ,which is deposited by the detonation gun process, the testing is performed on the dry rubber wheel abrasion testing machine at various varying parameter like the velocity of the rubber wheel, normal load applied on the machine and the coating component itself ,hence for the above a design of experiment matrix is formed, the solution of the matrix is done using the Taguchi method of optimization. This method not only determines the significant interactions and respective factors but also determines the significant interaction factor combination. Finally, genetic algorithm, a very popular evolutionary approach, is employed to optimize the factor settings for minimum specific wear rate under specific experimental conditions. The experimentation described is expected to be highly useful in the various large scale assemblies like the turbine assembly (the rotor part), and also in the areas such as construction aerospace sector.

Introduction

Mild steel is the most common form of steel. It is not brittle, it’s really hard, and it is cheap. It is often used when large amounts of steel are needed. Mild steel is a carbon steel typically with a maximum of 0.25% Carbon and 0.4%-0.7% manganese, 0.1%-0.5% Silicon and some traces of other elements such as phosphorous, it may also contain lead (free cutting mild steel) or sulphur (again free cutting steel called re-sulphurised mild steel). Mild steel (a so-called carbon steel) is a general term for a range of low carbon (a maximum of about 0.3%) steels[1] that have good strength and can be bent, worked or can be welded into an endless variety of shapes for uses from vehicles (like cars and ships) to building materialscontains a small amount of carbon. Due to the high usage of this in the industry it becomes very important for us to consider the wear property if it.Mild steel has always being area of interest and several methods are used to increase the structural and mechanical properties of it but no studies have so far being conducted on the abrasion wear[2] that is three body wear behavior for mild steel. Three body wear is generally defined as the property of erosion or abrading the metal surface by the action of a medium between the abrading surface ,generally direct contact erosion of the metal does not take place. Several methods and practices are utilized in the present scenario to increase the property of mild steel one such method is the thermal spraying[3-6] process where the layer of

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the given material is being embedded on the mild steel using high velocity by the help of the detonation gun process.

The present study aims at studying the wear behavior of mild steel and coating of tungsten (WC-Co)carbide and chromium carbide (Cr_3C_2-NiCr) [7-15] at various varying levels of speed and normal load applied on the testing machine using Taguchi method. Further the analysis of variance (ANOVA) is done to identify the most significant control factor and their interactions.

Experimental Details
Specimen preparation:
Substrate material and metalizing powder:

Commercially available mild steel was used as the substrate material and commercially available metalizing powders namely Cr_3C_2-NiCr (AMPERIT 585) and WC-Co (AMPERIT 518) were used for the purpose of coating whose chemical composition is given in table 3.1.

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

Sr. no.	Element	Substrate	WC-Co	Cr_3C_2-NiCr
1.	C	0.295	5-6	9.5-11.5
2.	S	0.025	_	_
3.	P	0.017	_	_
4.	Si	0.180	_	_
5.	Mn	0.99	_	_
6.	Ni	_	_	14-16
7.	Cr	_	3-5	Balance
8.	O	_	_	_
9.	W	_	Balance	_
10.	Co	_	8.5-11	_
11.	Fe	Balance	Max. 0.3	Max 0.5

For the purpose of coating on the mild steel specimen detonation gun spraying process is used.

Detonation gun spraying process:

A detonation gun consists of a water cooled barrel several feet long and about one inch in diameter with some associated valving for gases and powder, as shown schematically in Figure 1.A carefully measured mixture of gases, usually oxygen and acetylene, is fed to the barrel along with a charge of powder (usually with a particle size less than 100 microns). A spark is used to ignite the gas and the resulting detonation wave heats and accelerates the powder as it moves down the barrel. The gas is traveling at a supersonic velocity and the powder is entrained for a sufficient distance for it to be accelerated to a supersonic velocity as well, typically about 760 m/sec (2400 ft/sec). A pulse of nitrogen gas is used to purge the barrel after each detonation. This process is repeated many times a second.

The as-deposited surface roughnesses of D-Gun coatings vary with the type of coating from about 60 to over 300 micro inch, Ra. Although for many applications the coating is used as-deposited, most are ground or ground and lapped to 1 to 10 micro inch, Ra. Typical coating thicknesses range from about 0.002 to 0.020 inch, but both thicker and thinner coatings are used on occasion depending on thepecific application.

The best coating properties are achieved when the angle of deposition is close to 90 degrees to the surface. Because of the very high powder velocity, however, little degradation in properties is usually noted down to at least 60 degrees and useful coatings can be made at angles as low as at least 45 degrees.

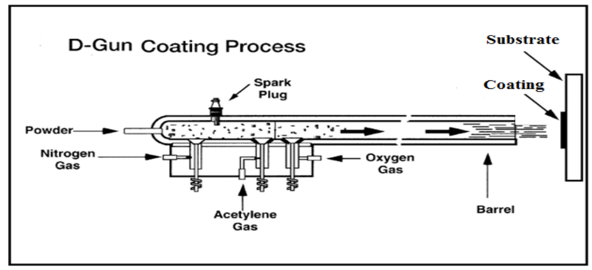

Fig.1: Schematic of Detonation Gun Process

Test Apparatus
Dry rubber wheel abrasion test:

To evaluate the performance of mild steel under abrasion condition wear tests are carried on dry sand rubber wheel abrasion testing machine as per ASTM G 65. The need for a high quality, well instrumented and commercially available machine to meet the requirements of ASTM Test Method G-65, "Conducting Dry Sand/Rubber Wheel Abrasion Tests", has been met with this machine. This test machine and test method is used to determine the resistance of materials to low load sand abrasion. It also has expanded capability and flexibility to conduct many other types of abrasive tests under a wide range of conditions. Reproduction ability depends critically on the nozzle and the loading mechanism; these parameters are highly constant with the machine.

The dry sand rubber wheel abrasion avoids the problem of particle explosion and particle size changes throughout the test because - throughout the test - new standardized sand is used. The Abrasion Test Machine can be modified with optional attachments to meet ASTM B-611, "Abrasive Wear Resistance of Cemented Carbides". For this test, a modification to the machine to run the test specimen in a wet slurry condition with a 6.65 inch steel wheel is required.

The Abrasion Test Machine with the slurry modification and special 7-inch rubber wheels meets or exceeds all requirements of the Society of Automotive Engineers "Recommended Practice for Determining Resistance to Abrasive Wear using Rubber Wheel Abrasion Machine" and ASTM G-105, "Conducting Wet Sand/Rubber Wheel Abrasion Tests". These methods are used to determine the resistance to abrasive wear of ferrous materials for tilling soils and earth moving and other applications involving slurry abrasive media. A schematic figure 2 depicts the machine in detail.

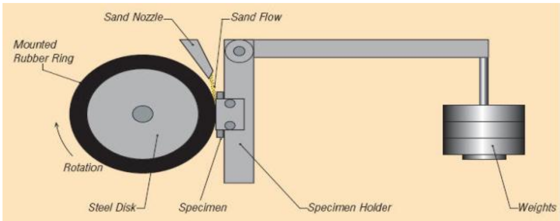

Figure 2 Schematic diagram of the abrasive testing machine

While conducting the experiment a series of tests are conducted with three sliding velocity 100rpm (1.1728m/sec), 150 rpm (1.9823m/sec) and 200rpm(2.35m/sec) under three different normal loading of 300gm(2.94N),1000 gm(9.81N) and 2000gm (19.62N).The material loss is measured using a precision electronic balance with the accuracy 0.1 mg and the specific wear rate (mm^3/Nm) is then expressed on the 'volume loss' basis as

$$\mathbf{Ws=\Delta m/\rho tV.F_n}$$

Where

Δm is the mass loss in the test duration (gm)

ρ is the density of mild steel and tungsten carbide and chromium carbide coating(gm/mm3)

V is the velocity (m/sec)

F_n is the average normal load (N).

Experimental design

Design of experiment is a powerful analysis tool for modeling and analyzing the influence of control factors on the performance output. The most important stage in the design of experiment lies in the selection of the control factors. The operating conditions, under which the erosion tests are carried out are given in table 1.The tests are conducted as per experimental design given in table 2 under room temperature.

Table 2. Control factors and levels in the experiment

Control factors	Level 1	2	3
A:Composition	Mild steel	Tungsten carbide cobalt(WC-Co)	Chromium carbide nickel chromium(Cr 3C-NiCr)
B: Velocity of wheel	1.729(m/sec), 100rpm	1.9832(m/sec), 150rpm	2.3542(m/sec),200rpm
C: Normal loading	2.94N,300gm	9.81N,1000gm	19.62N,2000gm

Three parameters i.e., sliding velocity, normal load, composition each at three level ,are considered in this study in accordance with $L_9(3^3)$ orthogonal array design. Three parameters each at three level would require 3^3=27runs in a full factorial experiment. Whereas, Taguchi factional experiment approach reduces to 9 runs only offering a great advantage. The experimental observations are transformed into a signal-to-noise(S/N) ratio. There are several S/N ratio depending on the type of characteristics. The S/N ratio for the minimum erosion rate come under smaller is better characteristic, which can be calculated as the logarithms transformation of the loss function as shown below.

Smaller is better characteristic: $\mathbf{S/N=-10\log 1/n(\Sigma y^2)}$.

Where n is the number of observations, and y is the observed data."Lower is better "(LB) characteristic, with the S/N ratio transformation, is suitable for maximization of erosion rate.

Table 3. Experimental design using L_9 orthogonal array

SI No	Composition A	Velocity B(rpm)	Normal Load C(gm)	Specific wear rate(mm^3/Nm)	S/N ratio (db)
1	Mild steel	100	300	**0.0002052**	**73.7565**
2	Mild steel	150	1000	**0.0022342**	**53.0176**
3	Mild steel	200	2000	**0.0000986**	**80.1225**
4	Tungsten carbide	100	1000	**0.0003688**	**68.6642**
5	Tungsten carbide	150	2000	**0.0000905**	**80.8670**
6	Tungsten carbide	200	300	**0.0002510**	**72.0065**
7	Chromium carbide	100	2000	**0.0001000**	**80.0000**
8	Chromium carbide	150	1000	**0.0000453**	**86.8780**
9	Chromium carbide	200	300	**0.0000400**	**87.9588**

Result and Discussions

From the above table the overall mean of the wear rate is found. Figure 3 shows graphically the effect of three control factors on wear rate and figure 4 shows the overall variation of the specific wear rate with velocity and normal load for various compositions. The analysis for the S/N ratio is made using the popular software specially designed for design of experiment applications known as MINITAB16.

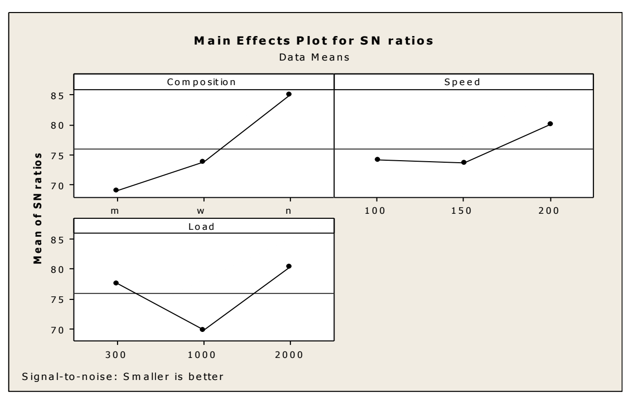

Figure 3 Effect of control factors on wear rate

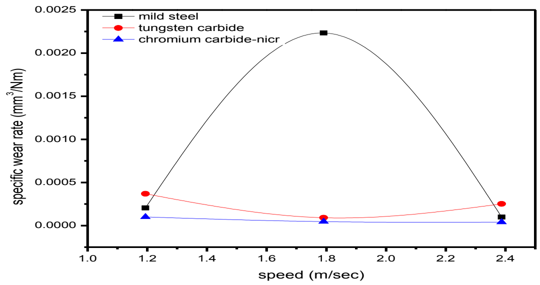

Figure 4a effect of speed on specific wear rate for various compositions

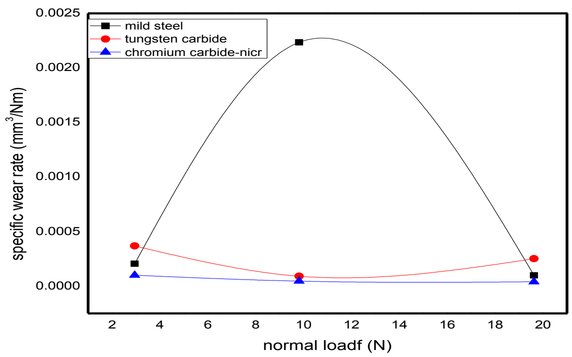

Figure 4b Effect of normal load on specific wear rate at various compositions.Analysis of the result leads to the conclusion that composition plays the major role in the wear rate analysis followed by normal load and then velocity as is evident front the table 5 below.

Table 4 Response Table for Signal to Noise RatiosSmaller is better

Level	Composition A	Speed B	Load C
1	68.97	74.14	77.55
2	73.85	73.59	69.88
3	84.95	80.03	80.33
Delta	15.98	6.44	10.45
Rank	1	3	2

The factor combination A_3, B3, C3 gives the minimum wear rate. As for the minimization rate is concerned factors A and C have significant effect whereas B has least effect.

ANOVA and the effect of factors

To understand the complete concept we need to visualize various factors and their interactions, so it is desirable to develop analysis of variance (ANOVA) table to find out the order of significant factors. Table 6 shows the result of the ANOVA with the erosion rate .the last column of the table shows the main effects are highly significant (all have very small p-values).

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Table 5 ANOVA table for wear rate

Source	DF	Seq SS	AdjSS	AdjMS	F	P
Composition	2	402.4	402.4	201.2	1.51	0.398
Speed	2	76.5	76.5	38.2	0.29	0.777
Load	2	175.7	175.7	87.9	0.66	0.603
Error	2	266.4	266.4	133.2		
Total	8	921.0				

From table 6 one can observe that the composition (p=.398), loading (p=.603) have great influence on wear rate and the velocity have the least effect on the wear rate.

Conformation test

The conformation test is the final test in the design of experiment process. The purpose of the confirmation experiment is to validate the conclusions drawn during the analysis phase the conformation test is performed by assuming a new set of factor setting $A_2B_1C_3$ to predict the wear rate. The estimated S/N ratio for the wear rate can be calculated with the help of following prediction equation:

$$\acute{\eta}_1=\dot{T}+(A_2-\dot{T})+(B_1-\dot{T})+(C_3-\dot{T})$$

Where $\acute{\eta}_1$ Predicted average

$\dot{T}$ Overall experimental average =75.91db

A_2=73.85, B_1=74.14, C_3=80.33(mean interaction of the factors at the designated level)

A new set of combination of factor level A_2,B_1,C_3 are used to predict wear rate through prediction equation and is found to be **$\acute{\eta}_1$=76.50db.**For each performance measure, an experiment is conducted for a different factor combination and compared with the result obtained from the predictive equation as shown in table 5.3.

Table 6 Result of conformation test for the wear experiment

	Optimal control parameters Prediction Experimental	
Level	**$A_2B_1C_3$**	**$A_2B_1C_3$**
S/N ratio for wear rate(db)	76.5000	76.4779

The resulting model seems to be capable of predicting wear rate to a reasonable accuracy. An error of .0221% for the S/N ratio is observed.

Conclusions

The present work is based on the abrasion wear property of mild 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 .In order to optimize the objective, mathematical model is developed and the contribution of the various factors on the wear rate are established.

The study further provides us with the best possible condition of the least wear in the material. Hence in accordance with our material we draw the following conclusions:

1 Wear in the mild steel is decreased by the use of coatings.

2 Coatings have high adhesion to the mild steel specimen.

3 Composition of the coating plays the most major role for the least wear in the specimen.

4 For optimized condition chromium carbide nickel chromium (Cr_3C-NiCr) has the least wear rate.

5 Optimized loading condition is 19.62N or 2000gm at the velocity of 2.3542m/sec or 200rpm for chromium carbide nickel chromium (Cr_3C-NiCr).

The following conclusions are in accordance with the levels taken by us and the limiting values taken for various factors.

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