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Research Paper

OPTIMIZATION OF ABRASIVE WEAR CHARACTERISTICS OF TUNGSTEN CARBIDE AND CHROMIUM CARBIDE BASED COATING ON H-13 STEEL USING DETONATION GUN PROCESS BY TAGUCHI METHOD

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Materials are the precious resources. In the industrial applications there are several materials that are being used and there mechanical and system property play a major role in successful implementation of any system. Abrasive wear results in loss of material by dynamic interaction of two surfaces with respect to one another. The present study generally works on the abrasion wear often called as a three body wear system on hot working steel (H-13) 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.

Keywords: Detonation gun process, thermal spraying, abrasion wear, Taguchi method

INTRODUCTION

Hot working steel (H-13) is widely used in industries. It is not brittle; it is hard and mostly used as dies material. It is known that under working condition dies are subjected to high pressure which causes wear of the die material. Coating can be done on material to increase the wear resistance and to make them corrosion resistance. Instead of coating hard chrome plating can be done. However, the hexa valent chromium associated with the chrome plating process is known to have detrimental effects on the environment and human health (Ishikawa *et al.*, 2005). Thermal spraying is a widely used industrial process for applying protective coatings to material surfaces. It is a process that involves the deposition of molten or semi-molten droplets

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of powder onto a substrate to form a coating (Wirojanupatump *et al*., 2001). In thermal spraying process the thickness of the coating may vary from 102-103 µm. The resistance against wear and erosion depends on the thickness of the coatings (Belli *et al.,* 2009)

Thermal spraying methods are a well-established processes and preferred technique for deposition of corrosion, wear protection, and thermal barrier coatings (Wórawski, 2008). Other methods of coating can be used but they have certain limitations like the main limitation of PVD is the size of a vacuum chamber, which restricted the size of coating elements (Ji *et al.,* 2006; Picas *et al.,* 2005).

Tungsten carbide and chromium carbide-based coatings are frequently used in various industrial fields such as the steel industry and aerospace industry to improve the resistance to sliding, abrasive and erosive wear (Ishikawa, 2007 ; Toma, 2001; Espallargas *et al.,* 2008).

Hot working steel(H-13) 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 (Harsha *et al.,* 2006) that is three body wear behavior for hot working 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.

The present study aims at studying the wear behaviour of hot working steel(H-13) and coating of tungsten (WC-Co)carbide and chromium carbide (Cr_3C_2-NiCr) (Krishna *et al.,* 2002 Torrance, 2002;Shu and Chen, 1997; Skulev *et al.,* 2005; Tobar *et al.,* 2006; Kim *etal.,* 2003; Kim and Kim, 1999; Murthy *et al.,* 2007; Harsha *et al.,* 2007) at various varying levels of speed and normal load applied on the testing machine using Taguchi method.

EXPERIMENTAL DETAILS

Substrate Material and Metalizing Powder

Commercially available hot working steel (H-13) was used as the substrate material and commercially available metalizing powders namely Cr_3C_2-NiCr and WC-Co were used for the purpose of coating whose chemical composition is given in Table 1.

Table 1: Chemical Composition of Metalizing Powders

S. No.	Element	Substrate
1.	C	0.35
2.	S	_
3.	P	_
4.	Si	_
5.	Mo	1.5
6.	Ni	_
7.	Cr	5.0
8.	O	_
9.	W	_
10.	V	1.0
11.	Fe	Balance

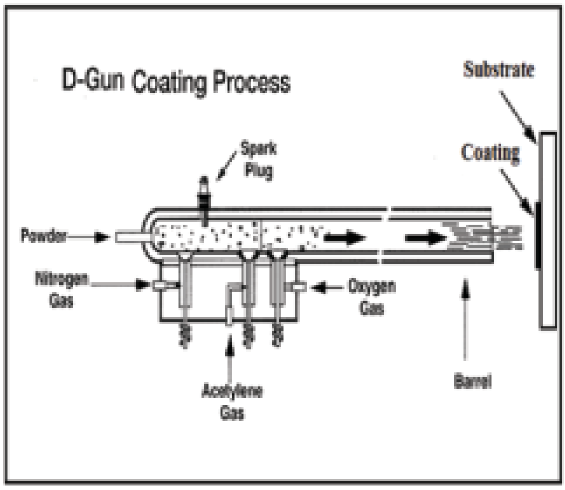
Chemical Composition (wt. %) of the Substrate Used

In this study the powder were sprayed by D-GUN, which is a several feet long barrel which is used to form coating on hot working steel (H-13).

DETONATION GUN PROCESS

A detonation gun consists of a water cooled barrel several feet long and about one inch in diameter with some associated valves 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 travelling 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/s). A pulse of nitrogen gas is used to purge the barrel after each detonation. This process is repeated many times in a second. Each individual detonation results in the deposition of a circle (disk) of coating a few microns thick and about one inch in diameter. The coating is made of many overlapping disks. Careful fully automated disk placement results in a very uniform coating thickness and a relatively smooth, planar surface. Detonation gun coatings thus consist of multiple layers of densely packed, thin particles tightly bonded to the surface. Primarily because of their high density and high bond strength, Praxair Surface Technologies' D- Gun™ coatings have become the standard of excellence for thermal spray coatings. The as-deposited surface roughness of D-Gun coatings varies with the type of coating from about 60 micro inch 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 micro inch to 10 micro inches, Ra. Typical coating thicknesses range from about 0.002 inch to 0.020 inch, but both thicker and thinner coatings are used on occasion depending on the specific application.

Figure 1: Schematic of Detonation Gun Process



The detonation gun process is called "line-of-sight" because the end of the barrel must be able to "see" the area being coated. 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.

TEST APPARATUS

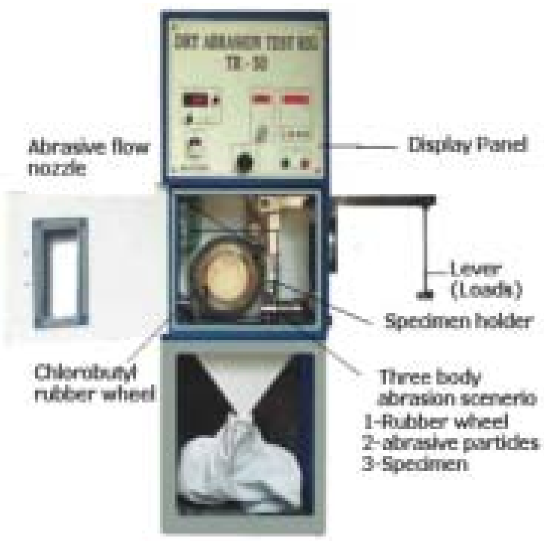
Dry Rubber Wheel Abrasion Test

To evaluate the performance of hot working steel (H-13) 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 100 rpm (1.1785 m/sec), 150 rpm (1.7678 m/sec) and 200 rpm (2.3571 m/sec) under three different normal loading of 1000 gm (54.936 N), 1500 gm (67.0023 N) and 2000 gm (79.0686 N). 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

$$Ws = \Delta m/\rho.t.V.Fn$$

where Δm is the mass loss in the test duration (g)

ρ is the density (g/mm^3)

V is the velocity (m/sec)

Fn is the average normal load (N)

EXPERIMENTAL DESIGN

Design of experiment is a powerful analysis tool for modelling and analyzing the effect of control factors on the performance output. The most important stage in the design of experiment is the selection of the control factors. The operating conditions, under which tests are carried out on the hot working steel (H-13), are given in Table 2. 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	H-13 steel	Tungsten Carbide Cobalt (WC-Co)	Chromium Carbide Nickel Chromium (Cr_3C-NiCr)
B:Velocity of wheel (m/s)	1.1785	1.7678	2.3571
RPM	100	150	200
C:Normal loading	54.936N, (1000g)	67.0023N (1500g)	79.0686N, (2000g)

Three parameters i.e., velocity, normal load, composition each at three level, are considered in this study in accordance with L9 (33) orthogonal array design. Three parameters each at three level would require 33=27 runs 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:

$$S/N = -10\log 1/n\ (\Sigma y^2).$$

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.

RESULTS AND DISCUSSION

From the Table 3 the overall mean of the wear rate is found. Figures 3 and 4 shows graphically the effect of three control factors on S/N R and wear rate and Figures 5 and 6 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 done by using the popular software known as MINITAB16.

Analysis of the result leads to the conclusion that composition plays the major role in the

Table 3: Experimental Design Using L9 Orthogonal Array

S. No.	Composition A	Velocity (rpm) B	Normal load(g) C	Specific wear rate (mm^3/Nm)	S/N Ratio (db)
1	H-13 steel	100	1000	.0005148	65.767
2	H-13 steel	150	1500	.0030363	53.240
3	H-13 steel	200	2000	.0031299	51.920
4	Tungsten carbide	100	1500	.0014929	52.694
5	Tungsten carbide	150	2000	.0005235	53.608
6	Tungsten carbide	200	1000	.0004081	54.367
7	Chromium carbide	100	2000	.0004843	54.991
8	Chromium carbide	150	1000	.0005566	55.510
9	Chromium carbide	200	1500	.0003708	55.995

Figure 3: Effect of Control Factors on S/N R

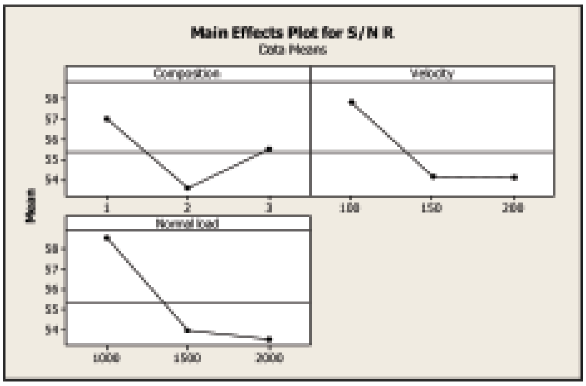


Figure 4: Effect of Control Factors on Specific Wear Rate

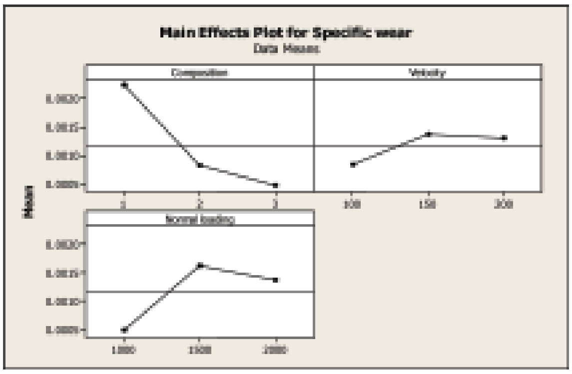


Figure 5: Effect of Speed on Specific Wear Rate for Various Compositions

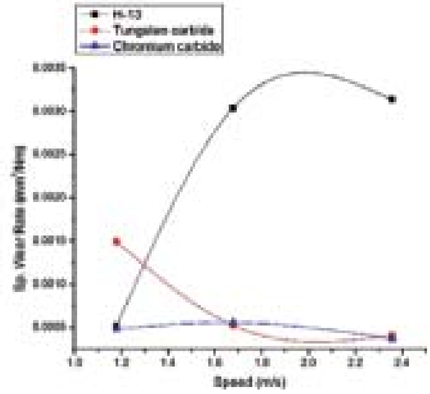
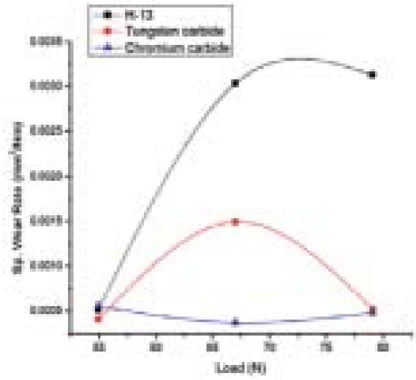


Figure 6: Effect of Normal Load on Specific Wear Rate for Various Compositions



wear rate analysis followed by normal load and then velocity as is evident from the Table 4.

CONFORMATION TEST

A new set of combination of factor level A2, B3, C3 are used to predict wear rate through prediction equation and is found to be u1 = 50.469732 db. 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.

Table 4: Response Table for Signal to Noise Ratio Smaller is Better

Level	Composition A	Speed B	Load C
1	51.920049	52.69436	54.3672192
2	50.69436	53.24032	52.69436
3	54.9906	51.920049	51.920049
Delta	$1.7567*10^{-3}$	$0.5217*10^{-3}$	$1.1401*10^{-3}$
Rank	1	3	2

Table 5: Result of Conformation Test for the Wear Experiment

	Optimal Control Parameters	
	Prediction Experimental	
Level	$A_2B_3C_3$	$A_2B_3C_3$
S/N R for water rate (db)	50.469732	49.32875

The resulting model seems to be capable of predicting wear rate to a reasonable accuracy.

CONCLUSION

Present work describes the effect of various coating on the hot working steel (H-13) under varying condition of load, velocity, and compositions. Main objective is to reduce the wear of the material, and to make it corrosion resistance. In order to optimize the objective, mathematical model is developed and the contribution of the various factors on the wear rate is established.

The results of this study are summarized as following:

1. Wear in the hot working 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.

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