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MICROHARDNESS IMPROVEMENT BY USING THERMAL SPRAYED NI AND AL COATINGS BY DETONATION GUN

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Abstract - *The present work was undertaken to increase the hardness of aluminium and nickel based coatings deposited by Detonation spray technique. The experimental work included deposition of Al2O3-TiO2 and Ni-Cr overlays of around 400 micron coating thickness, so as to achieve appropriate adhesion strength and hardness by using detonation gun spray technique (DS).*
Characterization of samples was made for further studies viz. as sprayed condition & post coating treatment. One of the hardfaced samples was subjected to post spray treatments of nitriding and compaction heat-treatment at 565° C for 2.5 hours and allowed to furnace cool, while another set of samples of both types of coatings was subjected to compaction at 12kN for 15 minutes. Systematic microstructural characterization of the coatings in the as-sprayed, nitrided conditions were carried out which included microhardness techniques in order to understand the effect of post treatment on the microstructure of these coatings.
It is found that the microhardness values of base metal are enhanced almost three times after hardfacing/coatings with the Al2O3-TiO2 & Ni-Cr, using DS, which further enhanced after post treatment of nitriding and compaction. In the case of nitrided and compacted samples, nickel based coatings showed 33% greater erosion resistance over aluminium based coatings. Thus post spray treatment of nitriding and compaction could result in higher hardness under given set of conditions.

Keywords- *Detonation Gun Spray, Erosive wear, Al2O3-TiO2 coating, Ni-Cr coating, Nitriding, Compaction, Microstructural characterization, Microhardness, Surface roughness.*

1. INTRODUCTION

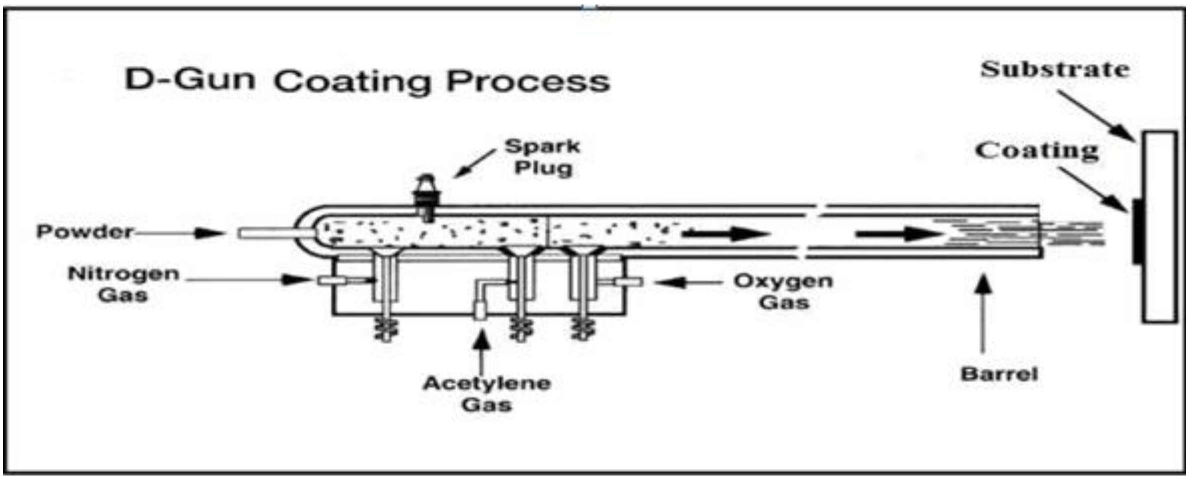
To extend the use of steel, a very important way is by means of coatings or overlays so as to protect the working surface from external factors or severe conditions such as gradual or sudden load. The intention of present work is to increase the hardness of nickel based coatings & aluminium based coatings on steel.

Al2O3-TiO2 coatings find extensive used in sleeve shafts, thermocouple jackets, electrical insulations etc. on the other hand the Ni-Cr coatings being relatively expensive than its competitor gives is more suitable for hydraulic machines, turbine parts and aero engine components. The coating materials thus selected for the present work so as to cater a variety of industrial applications. The substrate material selected was IS 2062 which is a type of low carbon steel and whose mechanical and metallurgical properties were studied before and after thermal spraying with the above mentioned metalizing powders by DS technique.

1.1 Detonation Gun Spray process.In the detonation gun spray coating process, pre encapsulated “shots” of feedstock powder are fed into a 1 m long barrel along with oxygen and a fuel gas, typically acetylene. A spark ignites the mixture and produces a controlled explosion that propagates down the length of the barrel. The high temperatures and pressures (1 MPa) that are generated, blast the particles out of the end of the barrel toward the substrate. Very high bond strengths and densities as well as low oxide contents can be achieved using this process.

1.1.1 Advantages:
(a) Increase in wear resistance by several times superior to other coating techniques currently available in Indian market.
(b) Dense microstructure (0.1-1% porosity).
(c) Extremely high coating bond strength (>10,000 psi).
(d) Very low substrate temperatures.
(e) Anti corrosion properties of ceramics and carbide coatings.
(f) Superior impact/ fretting/ erosion wear resistance.
(g) Negligible thermal degradation of powder during coating process makes the process suitable not only for spraying reactive powders but also to preserve the bulk micro structures.

1.1.2 Application Areas:
Proven areas where Detonation spray coating is highly established include Cable industry, Aerospace, Automotive, Chemical, Electronics, Glass, Marine, Metal processing, Microwaves, Military, Mining, Powder, Nuclear sector, Paper-pulp, Plastic, Printing, Pumps, Textile, and Cement Industry etc.



"Figure 1.1 Schematic of Detonation Gun spray coating Process"

1.2 Nitriding:
Nitriding is a surface-hardening heat treatment that introduces nitrogen into the surface of steel at a temperature range (500 to 550°C, or 930 to 1020°F), while it is in the ferrite condition. Thus, nitriding is similar to carburizing in that surface composition is altered, but different in that nitrogen is added into ferrite instead of austenite. Because nitriding does not involve heating into the austenite phase field and a subsequent quench to form martensite, nitriding can be accomplished with a minimum of distortion and with excellent dimensional control.

1.2.1 Principal reasons for Nitriding are:
(a) To obtain high surface hardness
(b) To increase wear resistance
(c) To improve fatigue life
(d) To improve corrosion resistance (except for stainless steels)
(e) To obtain a surface that is resistant to the softening effect of heat at temperatures up to the nitriding temperature.

1.3 Compaction:
The process by which the porosity of a given form of sediment is decreased as a result of its mineral grains being squeezed together by the weight of overlying sediment or by mechanical means.

2. LITERATURE REVIEW

Review of available published literature on any specific topic of research is the first valuable step to be taken to get an idea about the present status of that particular topic.

Venkataraman B. et al. (2001) compared the effect of grinding on the erosion behavior of a WC-Co-Cr coating deposited by HVOF and detonation gun spray processes on mild steel. The coatings in both 'as-coated' and 'as-ground' conditions were tested for solid particle erosion behavior. The erosion experiments were carried out using an air-jet erosion test rig with silica erodent at a velocity of 80 m/s. It was concluded that in 'as-coated' condition the microhardness of the WC-Co- Cr coating deposited by detonation gun spray process was slightly higher than that deposited by a HVOF process.

Desuza V.A. et al. (2003) Studied corrosive and erosive damage mechanisms during erosion-corrosion of WC-Co-Cr cermets coatings. It was observed that WC-Co-Cr thermal sprayed coatings provide good protection against wear and corrosion in liquid-solid impingement when compared with stainless steels.

Sundararajan G. et al. (2004) studied the tribological behavior of detonation sprayed coatings on mild steel. Coatings have been characterized in term of phase content and distribution, porosity, microhardness and evaluated for erosion, abrasion and sliding wear resistance. It was observed that the hardness and tribological properties of the coatings are more strongly influenced by the coating process parameters rather than microstructural parameter like porosity, phase content and distribution or powder particle size and shape of the starting particle. It was also concluded that any significant improvement in the coating properties should be possible only if the coating formation process is better understood

Dwivedi D. K. et al. (2007) studied the influence of the addition of chromium carbide (CrC) particles on the microstructure, microhardness and abrasive wear behavior of flame sprayed Ni-Cr-Si-B coatings deposited on low carbon steel substrate. It was observed that the wear behavior is governed by the material related parameters (microstructure, microhardness of coating) and test parameters (abrasive grit size and normal load). It was concluded that the addition of CrC reduces the wear rate three to eightfold. Wear resistance was greater against coarse abrasives at high loads than against fine abrasives.

Matthews S. et al. (2008) [Ref.14] investigated that Cr3C2-NiCr thermal spray coatings are extensively used to mitigate high temperature erosive wear in fluidized bed combustors, power generation and transport turbines. Cr3C2-NiCr coatings were to characterize the variation in oxide erosion response as a function of the Cr3C2– NiCr coating microstructure. Erosion wear test at 7000 C and 8000 C with erodentimpact velocities of 225m/s-235 m/s were conducted. It was observed that the erosion behavior of the oxide scales formed on these coatings was influenced by the coating microstructure and erosion temperature. Development of the carbide microstructure with extended heat treatment lead to variations in the erosioncorrosion response of the Cr3C2–NiCr coatings.

Liu Shenglin et al. (2010) [Ref.21] studied the dry sliding wear behavior and corrosion resistance of NiCrBSi coating deposited by activated combustion- high velocity air fuel spray process. The tribological behavior was evaluated using a HT- 600 wear test rig. It was bserved that Ni based coating produced by the HVAF technique have fewer pores and cracks and show good bonding to the substrate. It was also observed that the corrosion potential of the Ni based coating was higher than OCr13 Ni5Mo stainless steel due to passive film forming effect of Cr. The Ni based coating produced by HVAF spraying improved the corrosion resistance of the OCr13 Ni5Mo stainless steel.

Objective of the Present Work:
Based upon the problem formulated as discussed above, the following objectives were formulated:
1. To study the erosive wear behavior of Al2O3-TiO2 and Ni-Cr detonation sprayed coatings under the following conditions:
a) As-sprayed
b) Nitrided
c) Compacted
2. Microstructural characterization of the coatings under above mentioned conditions.
3. Microhardness evaluations of the coatings under above mentioned conditions.

3. EXPERIMENTATION

The problem formulation and objective finalization was made on the basis of the trials. Some trial runs were conducted to know about the limitations and capabilities of the available facilities and to finalize the parametric range or the work domain of the present work. After conducting the trials it was decided to undergo the detonation gun spray technique (DS technique) for the thermal spraying the hardfacing overlays of 80Ni-20Cr (AMPERIT 251) and Al2O3-3TiO2 (AMPERIT 742) on low carbon steel substrate of 5mm thickness. The coated samples were subjected to a series of experimentation and analyses to evaluate the effectiveness and behavior of overlays. Several coating characterization techniques like coating thickness measurement, surface roughness measurement, microhardness measurement are discussed below.

3.1 Substrate Preparation:
Prior to the coating, the mild 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 aluminum 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-175 mm.

3.2 Coating Procedure:
In detonation spraying, an explosive mixture of fuel gas i.e. C2H2, oxygen and powder is introduced in a long tube/barrel and ignited by a spark plug. Thoroughly cleaned substrate is fixed in the fixture. The resulting detonation-pressure wave heats and accelerates the entrained powder particles, which travel down the water-cooled barrel towards the substrate. Nitrogen was used to purge the barrel, between detonations, cycle of purging, injection, and detonation was repeated at a frequency of 3 to 6 Hz. Detonation spray process are hotter and yield longer particle dwell times than conventional flame spray process. The frequency and noise levels associated with detonation spray process is high so that they required be confined to acoustical enclosures. High particle velocities greater than 800 m/sec. were generated during the coating process.

3.3 Deposition of Coatings:

The grit blasted substrate was held suitably in a fixture and the coating deposition was carried out within the samples in the stationary condition with gun traversing to and fro position as per the working principle already discussed above in order to 29 obtain the desired coating thickness. The parameters of the procedure and other spraying conditions selected for the experimentation are given in table. no.

"Table No 3.1 Process parameters selected for Detonation spray process"

Sr. No.	Parameters	Ni-Cr	Al_2O_3-TiO_2
1.	O_2/C_2H_2 ratio	1:1.25	1:2.33
2.	Carrier gas(Nitrogen) flow rate (m^3/h)	2.1	3.2
3.	Spray distance (mm)	165	175
4.	Frequency of shots (shots/sec.)	3	3
5.	Firing rate (Hz)	1-10	1-10
6.	Coating thickness per shot (μm)	5-25	5-20
7.	Water consumption rate (lt/min.)	15-25	15-25
8.	Sound pressure level (dB)	150	150
9.	Relative humidity of ambient air (%)	50	50

3.4 Sampling of the Coatings:

After completion of the hardfacing by coating the substrate with the DS spray technique the coated samples prepared were subjected to various investigations viz. microhardness, surface roughness. As per the objectives defined after problem formulation. For the sake of simplicity of identification of various input conditions the prepared samples were further categorized as per the details given in the **Table 3.2**

"Table No. 3.2 Sampling of coated samples"

Sr. no.	SET(S)	Samples &condition of heat treatment
1.	SET-1	a) Ni-Cr - as sprayed
		b) Al_2O_3-TiO_2 - as sprayed
2.	SET-2	c) Ni-Cr - compacted
		d) Al_2O_3-TiO_2 - compacted
3.	SET-3	e) Ni-Cr - nitrided
		f) Al_2O_3-TiO_2 - nitrided

SET- 1 of samples

Ni-Cr and Al2O3-TiO2 coated as sprayed samples In SET-1, Ni-Cr and Al2O3-TiO2 coated samples were selected in the as sprayed condition and subjected to further analysis.viz. coating thickness, surface roughness, microhardness etc.

SET-2 of samples

In SET-2, after deposition of the coating, some of the Ni-Cr and Al2O3-TiO2 coated nitrided samples as sprayed coated samples of both Ni-Cr and Al2O3-TiO2 were nitrided at a temperature of 5650 C for duration of 150 minutes to minimize the effects of oxidation on the coating microstructure. Nitrogen is introduced into the surface of a coated sample by holding the sample at a suitable temperature in contact with a nitrogenous gas, usually ammonia. Quenching is not required for the production of a hard case. Because of the absence of a quenching requirement with attendant volume changes, and the comparatively low temperatures employed in this process, nitriding of steels produces less distortion and deformation than either carburizing or conventional hardening. Some growth occurs as a result of nitriding but volumetric changes are relatively small.

SET-3 of samples

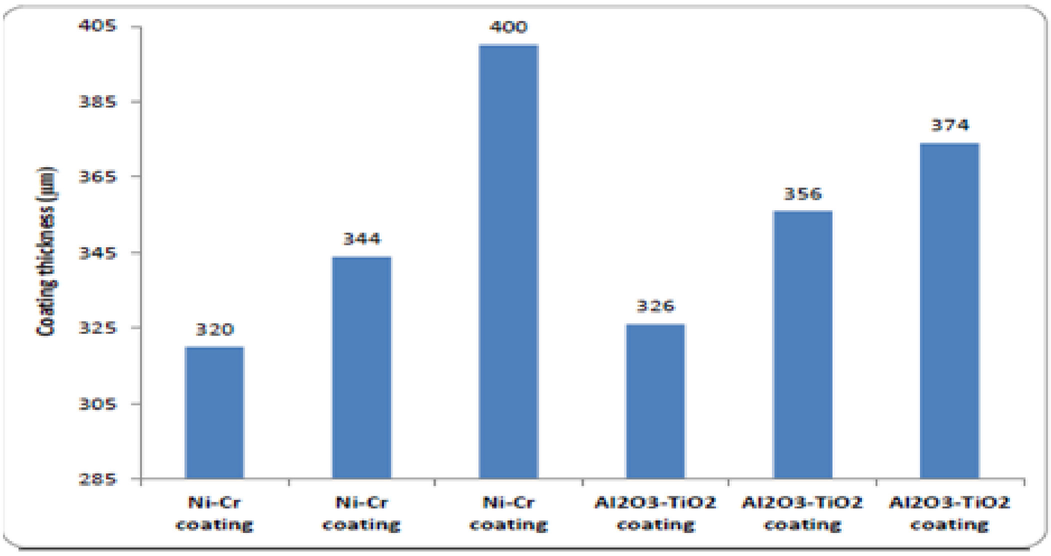
Ni-Cr and Al2O3-TiO2 coated as compacted samples

In SET-3, some of the coated samples of both the coatings Ni-Cr and Al2O3-TiO2 were subjected to compaction at 12 kN for 15 minutes with the digital Universal Testing Machine fitted with U Shaped plunger.

4. RESULTS AND DISCUSSION

4.1 Measurement of Coating Thickness:

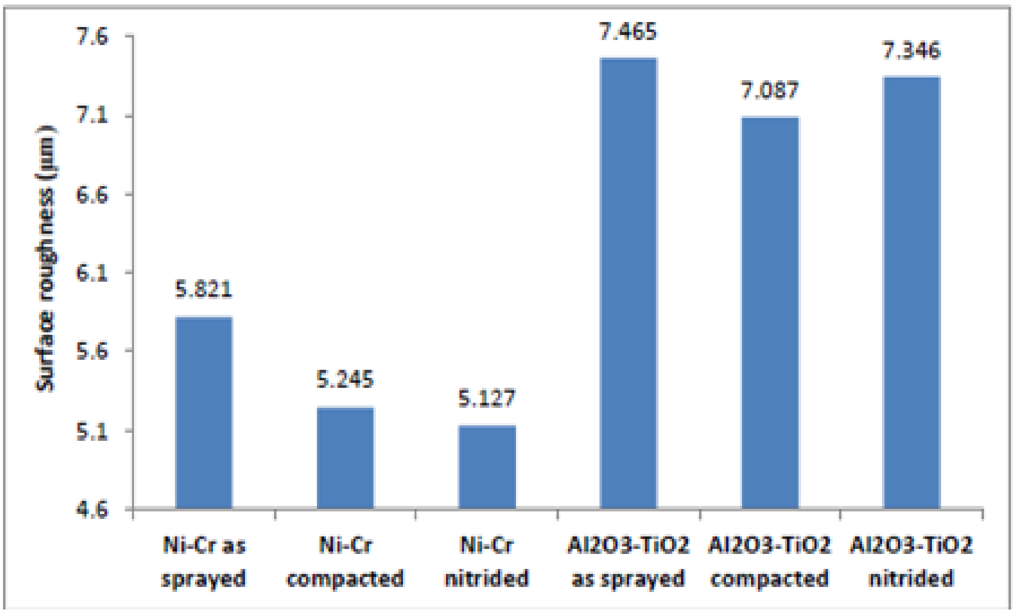
First of all the Ni-Cr and Al2O3-TiO2 coatings thickness were measured which were overlaid by the DS technique. The coating thickness was measured on the polished surface along the cross section of the samples with microprocessor coating thickness gauge Mini Test-600B. The thickness values obtained for coating deposited on samples are given in **Fig 4.1.** The The variations in the results obtained ranging from 280 to 400 microns which are based on the parametric selection. Below 320 micron samples were not considered due to non uniform thickness and inferior coating quality.



"Figure 4.1 Coating thickness of coated samples"

4.2 Surface Roughness Analyses:

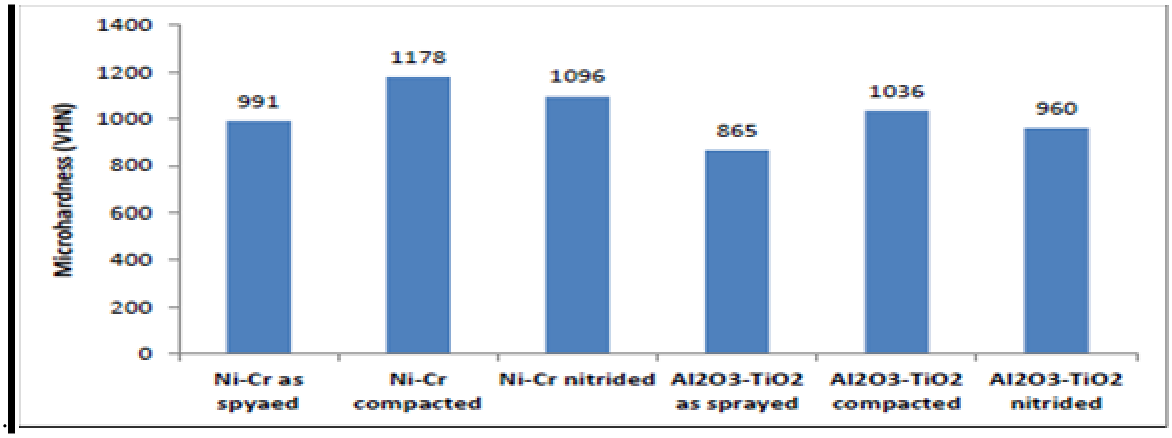
The surface roughness of the as sprayed, heat treated and compacted coatings were measured on the surface coder machine & the observations recorded are given below in **Fig 4.2**.



"Figure No. 4.2 Surface roughness value of as sprayed and post treatment samples"

4.3 Microhardness Evaluation:

The microhardness of the as sprayed, heat treated and compacted coatings were measured across the surface of the polished coated samples. The measurements were carried out using Vickers microhardness tester.



"Figure 4.3 Average micro hardness of as sprayed and post treatment samples"

5. CONCLUSIONS

All the detonation sprayed coatings under the selected range of parameters, possessed sufficient adhesion strength, good surface quality and adequate microhardness. In as sprayed condition Ni-Cr was found to possess better erosive wear resistance compared to Al2O3-TiO2 coating possibly due to better matrix properties of Cr binder material. The main conclusions based on the present work are listed below.

Microhardness of the substrate has improved to 3 times and 20 times respectively. i.e. microhardness from 295 VHN to 990 VHN

(a) Chromium carbide coatings responded well to the nitriding treatment of 565ºC and it was found that microhardness increased from 990 VHN to 1178 VHN, whereas surface roughness did not show any appreciable change.

b) Compaction treatment, which both types of the coatings were subjected to, resulted in increased microhardness, but no significant change on the surface roughness was observed. However compaction of Ni-Cr coatings resulted in decrease in the wear rate by approximately 27 % as compared to the assprayed condition.

b) The Ni-Cr coatings being relatively expensive than its competitor gives better coating surface, around 15% more hardness is suitable for hydraulic machines, turbine parts and aero engine components.

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