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Investigation of Al_2O_3-TiB_2 composite coating on W1 Tool steel deposited by Air Plasma Spraying

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ABSTRACT: The water hardening tool steel (W1) functions admirably where there are little parts and low temperatures. The water hardening tool steel has low resistance to softening at high temperatures (above 150°C). The softening point describes a temperature where the material will begin to experience appreciable changes in physical properties. The material become soft and stretchy, but will not completely melt. Therefore, softening is reduced by increasing the hardness and decreasing the thermal conductivity because hardness is the property of resisting plastic deformation. So Coating technology was considered to protect the tool from this problem. The metal coating is made using a mixture of Al2O3 - TiB2. A coating with high hardness and low thermal conductivity material is coated on W1 tool steel to prevent softening. The base material is coated with different thickness of the coated material by air plasma spraying process with varied coating process parameters to identify the best combination of the process parameters which results in better performance coating. The performance is assessed by conducting the wear test, corrosion test and micro hardness test for coated and uncoated specimens. Also micro structural analysis of the coated and uncoated specimens is done using FESEM microscopy.

KEYWORDS: W1 tool steel; Al_2O_3 and TiB_2; Air plasma spraying; surface coating.

I. INTRODUCTION

Water-hardening tool steels are also called group W steels. This gathering comprises of three kinds, to be specific, W1, W2, and W5. The principle alloying component found in group W steels is carbon. The water hardening tool steels are either high carbon steels or very low-composite carbon steels. The low composite substance of the water-solidifying tool steels yields barely any compound carbides and subsequently lower wear opposition and hardness contrasted with all the more profoundly alloyed apparatus steels. To expand the wear opposition and hardenability of the W steels, a modest quantity of chromium can be included. By including vanadium, the grain size is kept up, which improves the strength of the steels[1]. The group W steels have low protection from softening at high temperatures[4]. The softening point is that the physical properties of the material begin to experience changes at a certain temperature. The material will become soft and durable, but will not go completely melted. It very well may be effectively solidified by extinguishing in water. Be that as it may, this alloy undergoes some measure of twisting during quenching. W-steels are as yet sold, particularly for springs, yet are considerably less generally utilized than they were in the nineteenth and mid-twentieth hundreds of years.

This is incomplete because W-steels twist and break substantially more during extinguish than oil-extinguishedor air solidifying steels. So, these surface treatments are not befitting for certain applications and in this way they are covered for particular applications. There are different surface treatment innovations to improve hardness, corrosion and wear resistance of water hardening tool steel. These strategies have three classifications: mechanical, physical and chemical techniques, which are characterized as per the development mechanism of the layer on the material surface. Thermal spraying is a physical strategy, a procedure where materials are thermally

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liquefied into fluid beads and affected enthusiastically to the surface on which the isolated particles stick and consolidate. Atmospheric plasma spraying is a significant mechanical technique for getting ready defensive coatings to improve the performance of the component.

II. MATERIALS

WATER HARDENING TOOL STEEL (W1)

The W group comprises of three kinds, to be specific, W1, W2, and W5[4]. Commercially pure water hardening toolsteel (W1) was used as the coating substrate. The chemical composition of the substrate is given in the table 1[4].

Water hardening tool steels are delivered with various nominal carbon substances extending from 0.70 to 1.50%. Carbon content is the essential factor deciding properties and heat treatment reaction.

Table 1. Chemical composition of W1 tool steel.

Element	C	Mn	Si	Cr	Ni	Mo	W	V	Cu	P	S
Content (%)	0.70-1.50	0.10-0.40	0.10-0.40	0.15	0.2	0.1	0.15	0.1	0.2	0.025	0.025

Aluminium Oxide (Al_2O_3)

Aluminium oxide (or) alumina (Al_2O_3) discovers utilizes in the regulation of forceful and high-temperature conditions. The high hardness of alumina confers wear and abrasion resistance. The high "hot" hardness of alumina has prompted applications as tooltips for metal cutting and abrasives[5]. This is one of the ceramic materials which have high warm resistance. The mechanical properties improve essentially when Al_2O_3 is utilized as a covering compound.

Titanium Diboride (TiB_2)

TiB_2 is the steadiest of several titanium-boron mixes[6]. Similarly, as with other to great extent covalently bonded materials, TiB_2 is resistant to sintering and is generally densified by hot squeezing or on the other hand hot isostatic squeezing[6]. Because of its high hardness, incredible melting point, and chemical idleness, TiB_2 is a possibility for various applications. High hardness, moderate quality, and great wear obstruction make Titanium Diboride a contender for use in wear parts and, in composites with different materials and cutting apparatuses[6]. TiB_2 is a non-oxide ceramic material with low thermal conductivity. The mechanical properties, particularly hardness, can befundamentally improved when TiB_2 covering is utilized as a composite.

III. METHODS

The coatings were prepared using atmospheric plasma spraying which is a strategy that can alter the surface morphology and science. Right now, the plasma stream is utilized at high temperatures to extend particles toward and focused on a surface on which the particles fuse. Here the coating compound is made using the coating particles Al_2O_3 and TiB_2. The coating powder of aluminium oxide Al_2O_3 is taken up to 70% and titanium diboride TiB_2 is taken up to 30%. The substrate of water hardening tool steel is cleaned using CTC before coating. Carbon tetrachloride (CTC) is a compound generally utilized in industries as a cleaning operator. In power division, CTC is being utilized principally toclean the contacts of electrical types of equipment and so forth. After that grid blasting process is preferred, it may be a procedure where abrasive particles are quickened and mightily coordinated against a surface. These high-speed abrasive particles remove contaminants from the material's surface and condition the surface for subsequent finishing.

The process parameters for atmospheric plasma spraying technique are presented in table 2.

Table 2. Atmospheric plasma spraying process parameters of different coatings

Parameters	Sample 1	Sample 2	Sample 3
Current (A)	650	650	650
Voltage (V)	65-70	65-70	65-70
Powder feed rate (g/min)	30	30	30
Spray distance (cm)	8	8	8
Thickness (µm)	100	200	300

Where

A	- Ampere
V	- Voltage
g/min	- gram per minute
cm	- Centimeter
µm	- Micrometer

As per the literature, the overwhelming components which are having more impact on coating attributes in theplasma splashing process were recognized.

They are as per the following:

1) Current (A)
2) stand-off distance (cm)
3) Powder feed rate (g/min)

These are the essential operational parameters that come up with the liquefying and straightening of the powderparticles, controlling the coating qualities of plasma sprayed coatings.

IV. RESULTS AND DISCUSSION

To assess the quality of the coated specimens the microhardness test, Wear test, Corrosion test and SEM image analysis were carried out

Micro hardness

Microhardness estimations were worked by indenting on the metallographic cross segments under 0.5 kg load for 15s utilizing a Vickers microhardness analyzer. For every coated sample, Microhardness measurement is taken in 5 random areas. Distance between each indentation was kept significantly longer than the indentation diagonal to reduce the effects of the stress of nearby hardness indentations.

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Table 3. Test report of Vickers micro hardness testing

Coating thickness (µm)	Load values (Kg)	Observed hardness values (HV)					Average micro hardness Value (HV)
uncoated	0.5	243.4	243.3	242.8	253.6	254.7	247.56
100	0.5	369.8	345.2	383.7	350.5	352.3	360.3
200	0.5	320.8	314.2	290.8	293.5	304.4	304.7
300	0.5	267.1	265.7	263.6	308.0	314.2	283.72

The Vickers micro hardness test for coated and uncoated specimen carried out as per ASTM standard E384–16E and isshown in table 3. The effect of coating thickness on micro hardness when the applied load is 0.5 kg is shown in fig. 1.

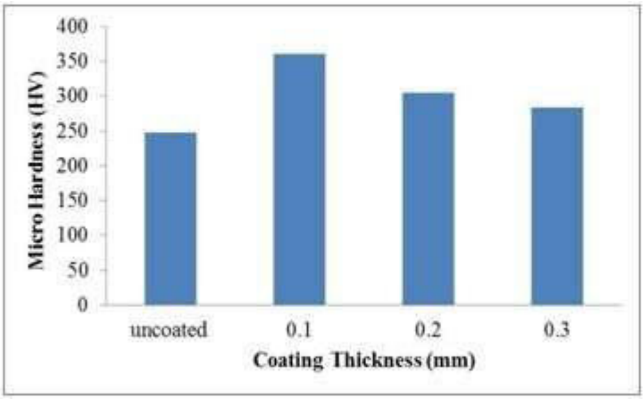

Fig. 1. Effect of coating thickness on Micro Hardness

Wear test

A pin-on-disc apparatus was utilized to assess the wear execution of coated and uncoated samples. As per the ASTM G99 standard, the test was completed utilizing a pin diameter of 10 mm and 30 mm long made of W1 tool steel. Here three distinctively coated samples and the uncoated sample were used to directing the wear test. The covered pins were made to slide as opposed to a circle made of Harden Steel (62–65 HRC). The samples were appended solidly in the pin-on-disc contraption and from there on the dead weight were applied by a lever system to press these samples against the rotating disc of 100 mm in diameter. Wear resistance tests were done with a typical load of F = 20 N for a sliding length of l=l005 m at a sliding distance of V = 200 r/min. A steady load of 20 N was applied for each test sample (coated as well as uncoated substrate). The Wear test results are shown in Table.4

Table 4. Test report of pin-on-disc wear test

Samples (in terms of thickness)	**Wear rate (mm³ / Nm)**	**coefficient of friction (COF)**	**Temperature (ºC)**
uncoated	5.083× 10-6	0.62354	150
0.1 mm	3.134× 10-6	0.48729	150
0.2 mm	2.541× 10-6	0.71558	150
0.3 mm	1.905× 10-6	0.74646	150

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The effect of coating thickness on wear rate is shown in fig. 2.

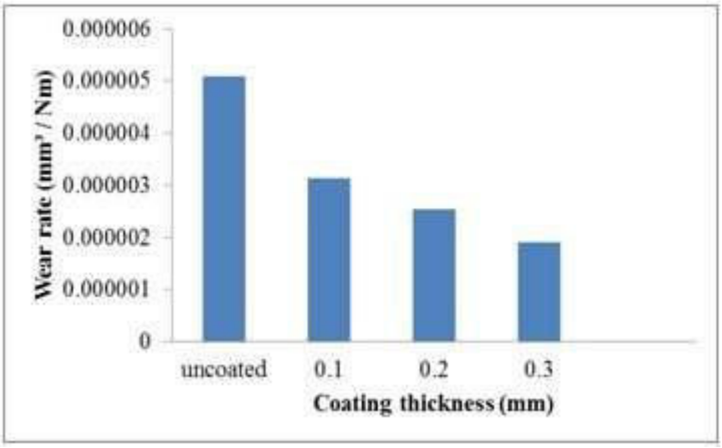

Fig. 2. Effect of coating thickness on the Wear

rateThe coefficient of friction for coated specimens is shown in the fig. 3

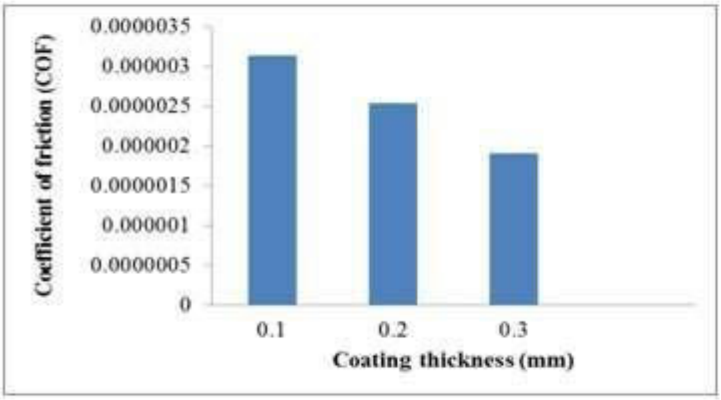

Fig.3 Coefficient of friction for coated samples

Corrosion rate

The easiest method for estimating the corrosion rate of a metal is to submerge the sample to the test medium (HCl corrosive) and measure the loss of mass of the material as an element of time. Different glass beakers of 250 ml limit were named uncoated, 0.1 mm coated, 0.2 mm coated and 0.3 mm coated each containing 100 ml of HCl arrangement. Following 168 hours, the examples were taken out and they are again cleaned and weighed. The corrosionrate (CR) is calculated from the formula given under. The average corrosion rate is obtained as follows:

$$\text{Corrosion Rate} = (K \times W) / (A \times T \times D)$$

Where:
K= a constant (3.45 x 106
mpy)T= time of exposure in
hours A= area in cm²
W= mass loss in
gramsD= density in
g/cm³

The weight-loss method of corrosion resistance test for both uncoated and coated specimens carried out as per ASTMstandard G31 and is shown in the table 5, respectively.

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Table 5. Corrosion rate of uncoated and coated samples

Samples (in terms of thickness)	Initial Weight W1 (g)	Final Weight W2 (g)	Mass Loss W1 - W2 (g)	Corrosion Rate (CR) (mpy)
uncoated	3.1948	3.1896	0.0052	1.3638
100µm	4.1667	4.1656	0.0011	0.2884
200µm	4.1846	4.1828	0.0018	0.4720
300µm	4.1562	4.1532	0.003	0.7868

The corrosion rate for Al_2O_3 and TiB_2 coatings of thickness 0.1 mm, 0.2 mm and 0.3 mm were 0.2884 mpy, 0.4720 mpy and 0.7868 mpy (mils per year) individually, while the corrosion rate of uncoated sample is 1.3638 mpy, in 100 ml of HCl at 168 hours. The corrosion rate of coated specimens is low when compared to the uncoated specimen. The 0.1 mm coated sample has excellent corrosion resistance, especially in coated specimens. The corrosion resistance of plasma-sprayed Al_2O_3 and TiB_2 coatings decreased significantly with expanding porosity, the roughness of the surface, and coating thickness

Microstructure analysis

The surface morphologies of atmospheric plasma showered coatings were analyzed utilizing Field Emission Scanning Electron Microscopy (FESEM) images shown in Fig.4, Fig.5 and Fig.6. The thickness of the coated Al_2O_3- TiB_2 layers was 0.1 mm, 0.2 mm and 0.3 mm. When contrasted with two other plasma-showered Al_2O_3-TiB_2 coatings, the particles in the 0.1 mm plasma splashed coating are profoundly melted. This coating indicated a dense and consistent microstructure. And also the presence of micro cracks on the coating surface is considerably less. Plasma sprayed coatings of 0.2 mm and 0.3 mm thickness are higher within the sight of insoluble particles contrasted with the
0.1 mm coating. Some huge clay particles could be seen in the plasma spraying process. FESEM pictures of coating show that most of the particles are circular and un-melted[12]. It is very well may be seen that the coating has exceptionally porous structure, which brings about a low degree of hardness to the coating. Moreover, such an enormous number of non-dissolved particles decline the adhesion of the sprayed coating to the substrate[12].The FESEM pictures of coatings show melted and imperfectly liquefied areas with the TiB_2 smaller scale particles remaining non-dissolved in the framework of coatings, which start from the high melting point of Titanium Diboride (around 2970 ºC).

The reasons for the presence of small amount of cracks are grid blasting of the substrate and the amount of the thermal expansion of TiB_2 which is less than the substrate (thermal expansion of W1, TiB2 are0.00000104/ºC, 0.0000081/ ºC)[12]. Therefore, their temperature tolerance is nearly the same, so the amount of thermal tension is significantly low[12]

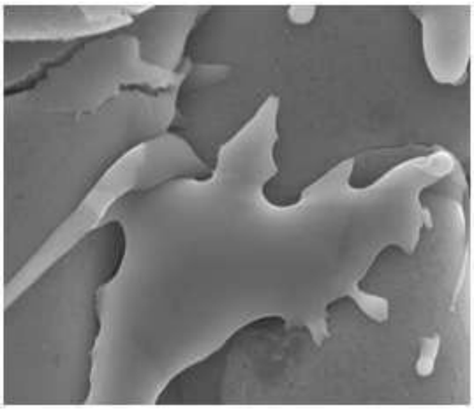

Fig.4. Field Emission SEM images of 0.1 mm Air plasma sprayed coating, on the scale of 10µm

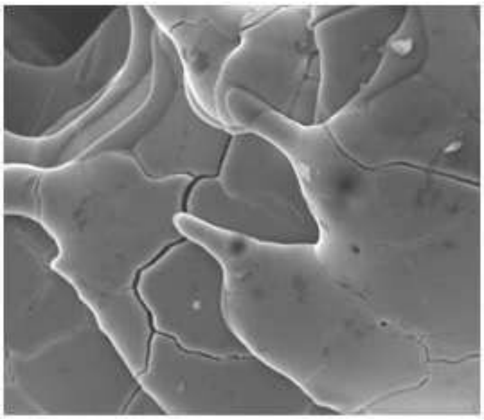

Fig.5 Field Emission SEM image of 0.2 mm Air plasma sprayed coating, on the scale of 10µm

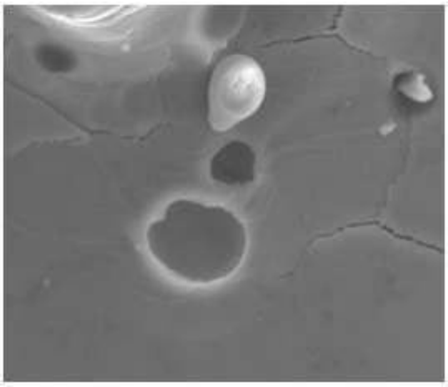

Fig. 6 Field Emission SEM images of 0.3 mm Air plasma sprayed coating, on the scale of 10µm.

V. CONCLUSION

The Al2O3-TiB2 coated W1 tool steels were subjected to different tests to assess the quality of the coating which in turn improves the life of the tool material. Based on the hardness, wear, corrosion and FESEM analysis it is found that the coating thickness has an impact on the properties and performance of the coating. The 1 micrometer (0.001mm) thick coating exhibits good adhesion, better wear and corrosion resistance and higher hardness than the other coatings.

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