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Titanium Carbide Laser Coating on Stainless Steel Substrate

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Abstract: *A sophisticated material processing technique called laser coating offers the ability to locally deposit different materials on extremely complicated and non-planar surfaces. It can be applied to restore or enhance wear, corrosion, and other surface-related characteristics of the base metal components. In this study, the primary attributes we take into consideration are surface hardness, wear resistance, and corrosion resistance. In the current work, TiC will be deposited on the base metal (stainless steel) using a pulsed Nd:Yag laser. By adjusting various laser coating parameters, such as laser power, laser scan speeds, etc., the resulting laser coating samples will be subjected to various mechanical (hardness, wear resistance) and metallurgical (microstructure and composition by SEM and XRD) studies*

Keywords: laser coating

I. INTRODUCTION

Superior surface qualities are required for engineering components in erosive and corrosive environments. Over the past few decades, composite coatings have been researched and produced in response to this necessity. Hard particles like oxides or carbides are often mixed into polymers, ceramics, or metal matrices to create composite coatings. Metal matrix composites (MMC) offer many benefits contingent on the properties of the matrix, including enhanced durability, resistance to corrosion, and elevated temperature tolerance, provided that the matrix is composed of high melting point metals like nickel and copper. Metal matrix composites include WC-Ni, WC-Co, and TiC-Fe. These novel materials are composed of a metal matrix that contains scattered non-metallic fibers, particles, or whiskers. circumstances. Metal-matrix composites must be able to sustain a load during operation without distortion, deformation, or fracture, as well as be able to sustain regulated friction and wear for extended periods of time without experiencing a seizure.

Coating

A coating is a covering that is put on an object's surface, also known as the substrate. Coatings are frequently used to enhance the substrate's surface qualities, including appearance, adhesion, wetability, corrosion resistance, wear resistance, and scratch resistance. Long-term surface protection is promised by several new coatings developed with nanotechnology [1]. In other instances, the coating is an integral component of the final result, particularly in printing procedures and the production of semiconductor devices (when the substrate is a wafer).

Laser coating

Utilizing cutting-edge material processing techniques, laser coating creates a structure that is incredibly dense, impenetrable, and has a strong metallurgical link to the base material. It is renowned for having extremely little dilution and little heat input. Laser coating offers a large variety of potential coating materials for various applications. Stainless steel, cobalt-based hard alloys (like Stellite-6 and 21), nickel-based super-alloys (like Inconel 625), self-fluxing alloys (like NiCrBSi), and cobalt-based hard alloys (like Stellite-6) are all often used for a variety of purposes. Minimal heat input, reduced influence on the mechanical qualities of the substrate, and automation system adaptability are some of the benefits of laser coating. By generating concentrated energy, the laser deposits the clad by melting the powder and substrate. Process parameters are important for both the microstructure and the quality of the clad.

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When compared to conventional or standard weld cladding or hard facing, laser coating offers a number of noteworthy advantages.

II. EXPERIMENTAL PLANNING AND PROCEDURE

EXPERIMENTAL PROCEDURE:-

There are three stages to the procedure:

SETTING UP THE ELECTRICITY BEFOREHAND

At this step, the base metal is coated or sprayed with powdered TiC or TiB2 diluted with acetone or alcohol. the TiC or TiB2 powder precursor suspended in acetone or alcohol. The steel (base metal) is sprayed with this powder precursor. There will be an average precursor thickness of 100–150 micrometers. Before laser processing, sprayed surfaces will be allowed to dry for one hour.

UTILIZING LASER TECHNOLOGY

The laser processing procedure at this stage will be performed using a Nd:Yag pulsed laser. After the laser's parameters, including power and scan speed, are correctly established, the laser will scan over the powder surface that has already been deposited and obtained from the preceding step.

DETERMINATION

Various measuring tools are used to measure the desired characteristics of the laser-coated surface, such as wear, hardness, and microstructure. We'll use XRD (X-ray diffraction technique) for phase analysis.

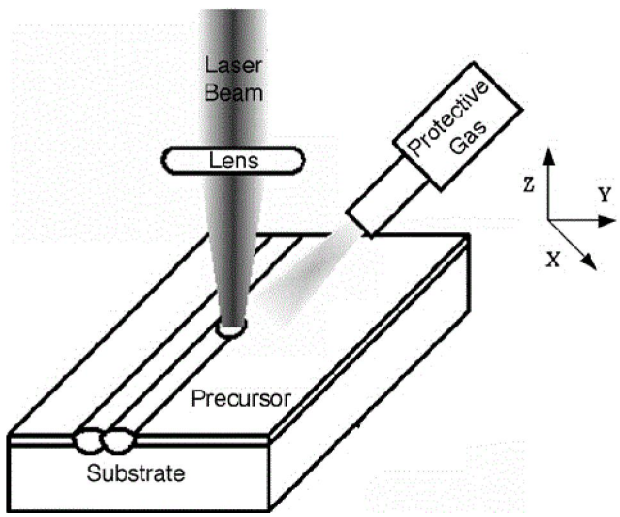

Fig 1 Schematic of laser coating process [14]

Physical properties of TiC

Density - 4.93 gm/cc

Melting point - 3067^{0}C

Modulus of elasticity - 439 GPa

Coefficient of thermal expansion 8.15 – 9.45× 10^{-6}.

Table:1 Chemical composition of AISI 304 stainless steel

Element Present	C	Si	Mn	P	S	Ni	Cr	Mo	Fe
Composition(%)	0.066	0.076	1.741	0.044	0.032	0.556	18.95	0.234	78.402

In order to determine the laser machine's limiting characteristics, such as peak power, frequency, scan speed, and ton, an experiment was first carried out on steel.

Different laser processing parameters for trial experiments:

Table 2: laser processing parameters for trial experiments

Laser surface No.	Spot dia (mm)	Peak-power (Kw)	Ton (ms)	Frequency (Hz)	Speed (mm/s)
SAMPLE 2					
1	1.5	1	12	14	11
2		2	6	14	11
3		1	12	9	11
4		1	12	14	9
5		3	12	5.6	2.4
6		4	12	4.3	2.4
7		3	12	5.4	4
8		3	12	5.4	11
SAMPLE 1					
1	1.5	1	12	15	11
2		2	6	15	11
3		1	12	10	11
4		1	12	15	9
5		1	12	15	2.4
6		1	12	15	5.9
7		0.3	12	15	11
8		1	12	15	11
9		0.7	12	15	9
10		0.5	12	15	9

Peak Power × Ton × Frequency equals Average Power
frequency is expressed in pulses per second.

High Peak-Power and low scan speed are not appropriate for coating TiC with a laser because they cause spattering of TiC due to low speed and high power in the aforementioned experiment nos. 5, 6, 7, and 8 of sample 2, which have a surface that is non-uniform in nature and extremely rough. We also noticed that in experiment nos. 7, 8, 9, and 10 of sample 1, where the peak power is less than 1 KW, a TiC layer is forming and it is easily peeled off since it does not integrate with the substrate surface. In order to determine the laser machine's limiting characteristics, such as peak power, frequency, scan speed, and ton, an experiment was first carried out on steel.

Fig 2 AISI 304 Steel samples prior to coating

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Fig 3 AISI 304 Steel samples after preplacing of TiC powder

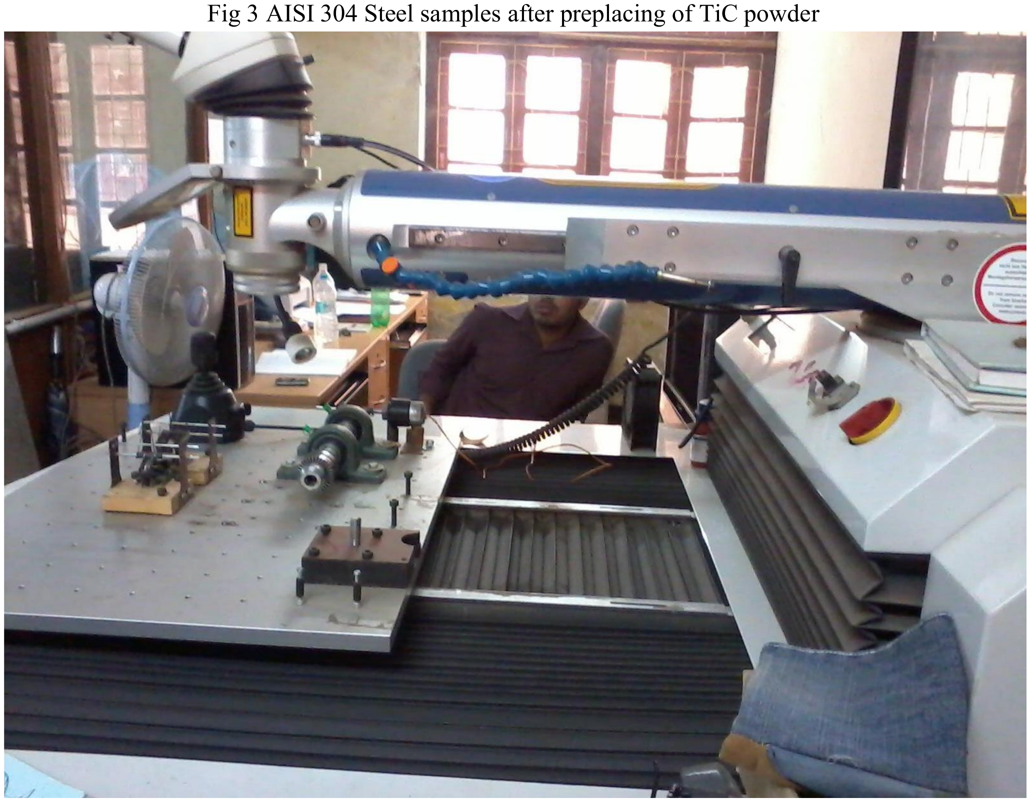

Fig 4. Nd-Yag pulsed laser experimental setup for development of coating

Neodymium-doped yttrium aluminum garnet, or Nd:Y3Al5O12, is a crystal that is utilized in solid-state lasers as a lasing medium. Since the two ions are comparable in size, the dopant, triply ionized neodymium, or Nd(III), usually replaces a tiny portion of the yttrium ions in the host crystal structure of yttrium aluminium garnet, or YAG. Similar to red chromium ions in ruby lasers, neodymium ions demonstrate the lasing activity in the crystal. Neodymium is typically doped into the crystalline YAG host at a rate of about 1% atomic percent.Nd:YAG lasers are optically pumped by means of laser diodes or flashtubes. These are among the most widely used kinds of lasers, with a wide range of uses. Typically, Nd:YAG lasers emit infrared light with a wavelength of 1064 nm. Nd:YAG lasers can run continuously or in pulses. throbbed Usually, Nd:YAG lasers are run in a mode known as Q-switching: In order for an optical switch to open, it must first wait for a maximum population inversion of neodymium ions within the laser cavity. Once through the cavity, the light wave can depopulate the excited laser medium to its maximum population.It has proven possible to achieve 250 megawatt output powers and 10 to 25 nanosecond pulse lengths in this Q-switched mode. It is possible to effectively double the frequency of the high-intensity pulses to produce higher harmonics at 355 and 266 nm or laser light at 532 nm. The wavelength ranges where Nd:YAG absorbs most are 730–760 nm and 790–820 nm. Krypton flashlamps produce more light in those bands at low current densities than do xenon lamps, which are more widely used. Xenon lamps emit more light at approximately 900 nm. Consequently, the former are better at pumping Nd:YAG lasers. The material's neodymium dopant content varies depending on its intended purpose. Doping for continuous wave output is far less than that of pulsed lasers.

Fig 5: Steel sample-1 after coating
(Trial experiments)

Figures 4 and 5 display samples coated with TiC using a laser.These are samples that were obtained following the application of TiC coating.

Table 3: laser processing parameters for TiC coating of AISI 304 steel

Experimentno	peak power(KW)	Ton(ms)	frequency(Hz)	scan speed(mm/s)
1	1.2	9	15	4
2	1.2	9	15	6
3	1.2	9	15	8
4	1.2	9	15	10
5	1.2	9	18	4
6	1.2	9	18	6
7	1.2	9	18	8
8	1.2	9	18	10

Peak Power × Ton × Frequency equals Average Power frequency is expressed in pulses per second.
Example of a computation

Exp 1's average power is $15 \times 9 \times 1.2 = 162$W.

On the samples in this case, eight experiments are carried out. In the first four experiments, we varied the scan speed while maintaining the peak power and Ton to determine the impact on coating formation on the base metal. In the following four experiments, we increased the power slightly from the previous value while maintaining its constant value for all four experiments, and we also increased the frequency to 18 from the previous 15 while maintaining its constant value for all four experiments. trials, and just as in the first instance, we changed the speed to see how it affected the type of coated surface that developed on the base metal. Various tests are then conducted to determine the kind of coated surface that forms on the base metal as well as its characteristics.

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Fig 6-After coated sample of AISI 304 steel

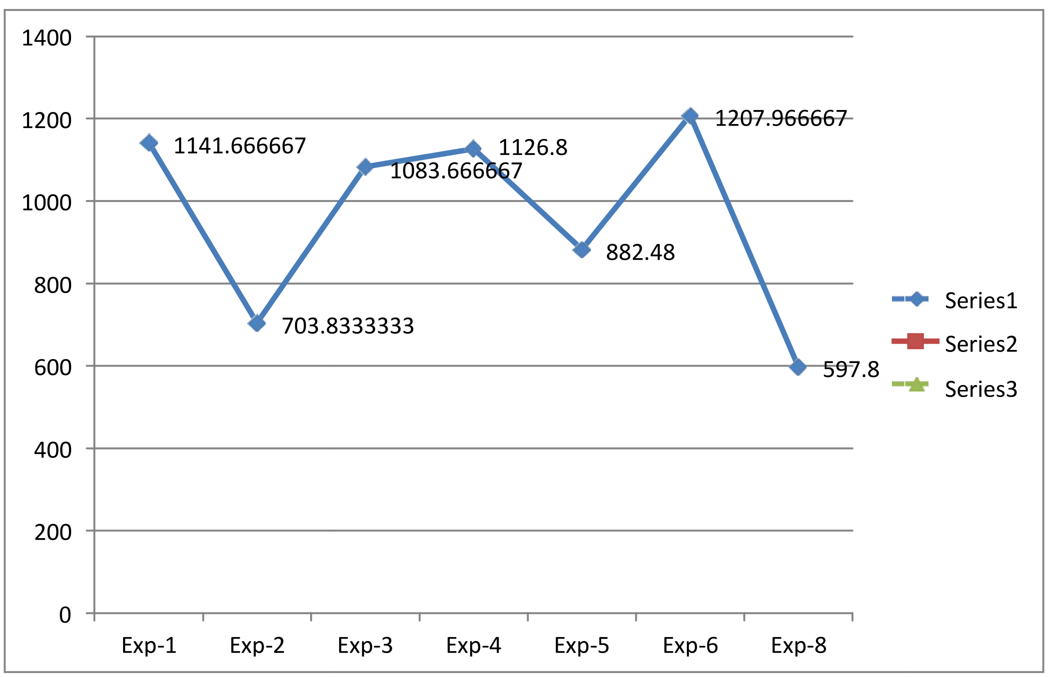
III. RESULT & CONCLUSION

Micro hardness analysis

Table 4: Micro hardness values obtained; all values in VHN* units

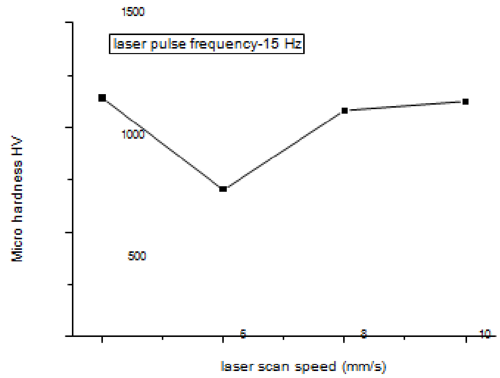
Test no	Exp-1	Exp-2	Exp-3	Exp-4	Exp-5	Exp-6	Exp-8
1	1141	732	1097	1144	1125.7	1004.1	643.9
2	1065	529	1095	1343	891	1249	570.1
3	998	567	993	892	843.1	1361.6	579.4
4	1242	848	693	1423	788	1532.6	----
5	1369	748	1155	835	766.3	1241.8	---
6	1029	803	1475	-----	----	858.7	---
Averagevalue	1142.6	702.8	1082.6	1126.7	882.3	1207.9	597.8

Vickers Hardness Tester is used to calculate the micro hardness values for various trial surfaces. The results are tabulated and displayed in Table 3. after the experiment no. and micro hardness values are plotted on the graph as indicated.

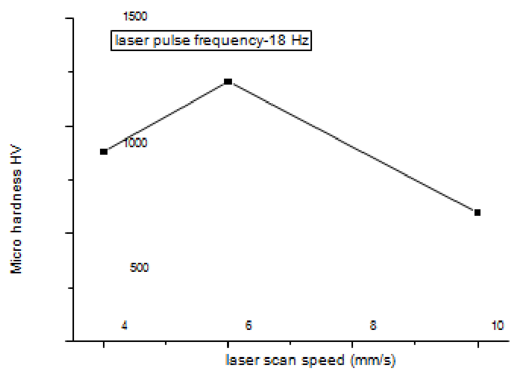


Graph 1: micro hardness vs experiment no., (micro hardness values are in VHN)

Plotted in the above graph are various micro hardness values from the respective experiments. The micro hardness value of the coated surfaces varies from 597.8 to 1207.967 VHN (Vickers Hardness Number), according to these statistics or graphical representation..



Graph 2: Micro hardness vs laser scan speed at constant peak power (1.2 KW) and frequency(15 Hz)



Experiments with varying laser scanning speeds were carried out at a frequency of 15 Hz, a constant peak power of 1.2 KW. Graph 2 shows the micro hardness values of the coated surface created with various laser scanning speeds. This graph shows that the micro hardness of the coated surfaces is nearly constant at peak power of 1.2 KW and frequency of 15 Hz. This suggests that the micro hardness of the produced surface is not reliant on the laser scan speed.

SEM (scanning electron microscope) micrograph

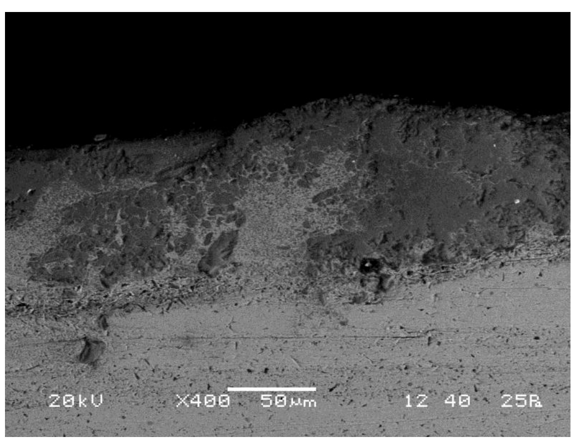


Fig 7:- SEM micrograph at the cross section for TiC coating on AISI 304 steel processed with withlaser power 1.2 kW, frequency 15 Hz and scan speed 8 mm/s

As we travel from the coated surface towards the substrate or the base metal down to a specific depth, Figure 7 illustrates the creation of a TiC layer on the surface, which is integrated or dispersed with the metal. Additionally, this figure demonstrates that the base metal has a homogeneous layer development.

AISI 304 steel has been coated uniformly with TiC using a laser coating method.

At a frequency of 15 Hz and a peak power of 1.2 KW, the microhardness of the surface created is not affected by scan speed.

The micro hardness of the surface formed at a peak power of 1.2 KW and a higher frequency of 18 Hz is largely dependent on the scan speed; a medium scan speed is recommended to obtain a well-coated surface with a high micro hardness.

The TiC layer that forms is non-uniform and discontinuous in nature at high speeds and high peak powers.

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