Tungsten Inert Gas (TIG) Assisted TiC-Ni Coating on AISI 304 Stainless Steel

A Thesis Submitted in Partial Fulfillment of the Requirements for the Award of the Degree of

Bachelor of technology

In

Mechanical Engineering

By

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DECLARATION

I ***Soumya Ranjan Gochhayat*** solemnly declare that the report of work entitled "***Tungsten Inert Gas (TIG) Assisted TiC-Ni Coating on AISI 304 Stainless Steel"*** is based on the work carried out for my final year project under the supervision of Dr. M. Masanta of Mechanical Engineering department, NIT Rourkela.

I affirm that the announcements made and conclusions drawn are a result of my project work. I further pronounce to the best of my insight and conviction that the report does not contain any piece of any work which has been now submitted for postulation assessment in this institute.

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Certificate

This is to certify that the report entitled " ***Tungsten Inert Gas (TIG) Assisted TiC-Ni Coating on AISI 304 Stainless Steel"*** submitted by ***Soumya Ranjna Gochhayat*** to National Institute of Technology Rourkela, is a record of confide research work carried out by him under my supervision for the partial fulfillment of the requirements for the Award of the Degree of Bachelor of Technology in Mechanical Engineering at National Institute of Technology, Rourkela. The representation of this report has not been submitted in any other University and/or Institute for the award of the any degree or diploma.

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Soumya Ranjan Gochhayat

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ABSTRACT

Metal components very often lose their functionality through wear by various modes such as abrasion, impact or corrosion. To counteract such problems, and there by to extend the service life, modification of surfaces are frequently done. This surface engineering approach finds application across many sectors namely defense, mining, steel, power, cement, petrochemical sugarcane and food. Generally the base material of the component is selected on the ground of strength and cost involved, while the details of the surface properties are adopted for local tribological conditions to which the vulnerable section will be subjected during its service period. There have been wide range advancement in surface engineering technology to square up surface failure in steels. But each technology that evolved has its own limitations. Deposition of thin hard coatings of 0.5 mm can improve tribological properties in terms of low friction and wear resistance. But in case of light metal alloys, when the load is high, the coating may fail by deformation. In such cases reinforcement of metals with ceramics can increase the physical and surface properties like strength, stiffness, wear resistance, high temperature strength and a reduction in weight. Over the years, modification of the matrix close to the surface, as well as reinforcement, has been introduced. The addition of ceramic particles into the molten metal surfaces to form a metal matrix composite (MMC) is a very popular one and is widely used worldwide. The formation of MMC meets the specifications required for specific applications. Tungsten Inert Gas (TIG) welding method produces a small modified hemispherical surface which has a width of few millimeters. It also incorporates less cost compared to laser treatment, so widely in practice. TiC is used as a reinforcement material as it has received some attention being a wear resistance substrate. Ni is used as it is a very good binder that produces a well-mixed Tic-Ni mixture. TIG process was used to melt the TiC-Ni MMC on an AISI 304 stainless steel. This achieved an approximate micro hardness value of 800HV.

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1. Introduction

TIG welding: Tungsten Inert Gas welding (TIG) which is also known as Gas Tungsten Arc welding (GTAW) is an inert gas shielded arc welding process. It is also a homogeneous fusion welding process. Here an arc is established between a non-consumable tungsten electrode and the work piece. Tungsten is alloyed with thorium or zirconium for better current carrying and electron emission characteristic. This welding process is done with or without use of filler material. Here arc length is constant and stable which is easy to maintain. Since no flux is employed, no special cleaning or slag removal is required.so very clean welds are produced. Except highly reactive Al, Mg all other metals can be welded. Generally straight polarity is used. Torch is water cooled and the shielding gas used is Argon.

1.1 Different techniques used for surface coating

In the present days, various surface engineering techniques are in practice to improve the surface properties. Out of those, very popular methods are physical vapour deposition (PVD), chemical vapour deposition (CVD), plasma spraying, electro-deposition, carburizing, nitriding, flame/induction hardening, galvanizing, diffusion coating, etc. few the above are briefly explained below:

- Physical vapour deposition (PVD):
  It is a method of producing metal vapour which can be deposited on an electrically conductive material as strongly bonded pure metal or alloy coating.

- Chemical vapour deposition(CVD):
  It is a chemical method of producing thin-film coating as an aftereffect of responses between different vaporous stages and the heated surface of substrates inside of the CVD reactor. Since diverse gasses are transported through the reactor which brings about unmistakable covering layers on the tooling substrate. For instance, TiN is framed as a consequence of the accompanying compound response as a result of thefollowing chemical reaction:

$$TiCl_4 + N_2 + H_2 \rightarrow TiN + 4\ HCl + H_2$$

- Thermal / Plasma spraying:

In this technique the liquid metal is splashed onto a surface to give a coating. Material as powder is infused into a high temperature plasma fire, where it is quickly heated and quickened to a high speed. The hot material effects on the substrate surface and quickly cools shaping a coating.

- Electrodepositing:

It is a sophisticated process which involves dipping the coating into a conductive waterborne coating solution. Electro deposition coating is also called electro coating.

- Carburizing:

It is a process of adding Carbon to the surface by surface heat treatment.

- Nitriding:

It is a process of diffusing Nitrogen into the surface of steel by heat treatment process.

However, these techniques offer many limitations, e.g. some require high processing time, high energy input, bulk consumption, poor precision, and inability for automation. On the other hand Tungsten Inert Gas (TIG) surface engineering techniques (e.g. TIG cladding or TIG alloying) which are based on applications of electric arc are free from many of these restraints.

TIG assisted surface engineering offers several advantages over other surface modification techniques.

I. The total heat input from TIG is low i.e. the heat affected zone is small, bringing about negligible contortion and in this way extremely nearby treatment without influencing the mass substrate is conceivable.
II. The processing time is very less and can be automated.
III. Complex support systems are not required.
IV. Minimal weakening of the substrate by the coating material is conceivable however delivering a sound interface is acquired between the coating and substrate which are metallurgically fortified.
V. The surface microstructure can be well controlled by varying process variables such as current, power, scan speed and coating powder composition.

1.2 Different types of TIG cladding process

Initially we saw different types of surface engineering techniques. Among these we found that TIG cladded surface engineering technique can be classified as follows:

i. By preplaced powder method
ii. Wire feed
iii By powder feeding method

Preplaced powder

The first technique for metal conveyance is a genuinely basic and clear method. This is thought to be a two-stage cladding system. The main stage involves the covering of the substrate with the preplaced powder i.e. the electric arc trades its essentialness to the powdered metal and melts the powder. The second stage is the heat exchange of the fluid covering to the substrate. At that point covering begins to set. Therefore an incomplete metallurgical bond between the covering and surface is shaped.

Wire feed

The second strategy for clad conveyance is through a wire feed. The wire is fed from a drum to the laser. This is the first of a few issues that wire nourishing experiences amid the cladding procedure. The wire drum must be sufficiently extensive to anticipate issues with any plastic deformity and being in accordance with the substrate development to consider smooth encouraging. The biggest issue that encompasses the wire feeding is the way the liquid wire acts at the tip of the wire. The liquid metal does not stream well on the substrate and this prompts a high weakening of the clad into the substrate.

Powder feeding method

The third method for the coating material comes back to the standard of powdered metal. At the same time, the powder is infused into the way of the shaft. The powder is brought through the tubing utilizing an inactive gas that permits the covering material to be blown into the way of the pillar. The blown powdered metal particles are part of the way dissolved by the shaft. The laser makes a little liquefy pool on the surface of the substrate that completely dissolves the powdered metal.

Advantages of preplaced powder coating:

- It is cost effective
- Its procedure is simple
- It can be used for testing purposes for small scale production of coated materials

1.3 TIG cladding coating layer properties

Some of the important properties and characteristics of the TIG coating produced by the preplaced powder over the substrate are mentioned in the Table 2.

Table 2: Major properties of TIG cladding

Geometrical properties	Mechanical properties	Metallurgical properties	Qualitative properties
coating height dilution roughness	hardness residual stress wear resistance tensile strength	microstructure dilution grain size homogeneity corrosion resistance	porosity cracking

The TIG cladding properties are described below:

1. Coating height: With increase in scan speed in TIG cladding, coating height increases above the substrate surface and the melts depth within the substrate decreases. In contrast with increase in power input, coating height decreases and melts depth increases.
2. Dilution of laser coating: Spreading of melt pool on the substrate happens after the premixed clad powder over the substrate is exposed to the arc. TIG clad layers properties are influenced by dilution. Dilution decides the quality of the coating layer which decides the wear resistance of the surface so delivered. It is found that expanding the territory of dilution for the particular point of confinement, the bond strength between clad layer and substrate will be expanded. Though applications that oblige great corrosion or oxidation resistance, in them clad layer arrangement must have greatest rate of coating material.
3. Roughness: Roughness signifies lack of surface finish. Thus minimizing the roughness improves the surface quality.
4. Hardness: The hardness of the coating layer is impacted by the kind of coating material and the scanning speed.
In the event when the scanning speed is low, then the heat input is higher at a constant current condition. Similarly increasing the current at a constant scan speed heat input is more. During the procedure the powder particles show signs of improvement and disintegrated into the mass of the surface layer. Furthermore, along these lines for this situation reinforcing impact is more. Microhardness increments with the increase of current at a constant can speed because of uniform melting.
5. Wear resistance: Wear resistance determines the life of the coated substrate. It depends on the ceramic material used for coating over the substrate and the laser treatment parameters.
6. Crack formation: Cracking is caused due to fast cooling rates and residual stresses. Crack

prevention is important, because cracks in the coating surface initiate corrosion fracture and reduce fatigue strength.

7. Residual stress: Amid heading the territory of substrate which is exposed to TIG gets warmed and expands. Notwithstanding, it is obliged by the frosty encompassing substrate region and gets to be pushed in pressure until liquefying happens that unwinds the stresses. It is during the hardening that the tensile stresses are framed because of shrinkage of the melt pool which is restricted by the metallurgical bonding with the substrate. Also, in this way the high thermal gradient involved during the procedure produces residual stresses. These residual stresses influence the mechanical properties, for example, fatigue, creep and brittle fracture on the surface.

8. Homogeneity: A watchful choice of handling parameters brings about coating layers which has a homogeneous chemical composition that is free from imperfections.

9. Porosity: Presence of holes in the coating layer is being alluded to as porosity. It is for the most part as a consequence of the arrangement of gas bubbles that are caught in the weld pool.

2. Literature review

2.1 Metal Matrix Composites

Recently with development of metal matrix composites (MMC), high performance depositing composite coatings on low grade substrate materials has become an interesting area of research. Particularly, various carbide reinforced MMC coatings have been developed to modify wear and corrosion resistance [1-4]. Metal–matrix composites (MMCs) fortified with hard earthenware particles have gotten significant interest in light of the fact that they can offer enhanced quality, stiffness and wear resistance contrasted with their counterparts. Nonetheless, a poor strength of metal network composite forces a genuine limitation on creation of the mass materials for auxiliary application [5]. Then again, wear is a surface-subordinate debasement that may be enhanced by a suitable alteration of the small scale structure and/or arrangement of the close surface locale. Henceforth, rather than the mass fortification, if a composite layer is produced on the close surface locale it would upgrade the wear resistance property fundamentally without influencing the durability [6]

2.2 Laser cladding process

Laser composite surfacing is a procedure where a powerful laser beam is utilized as a wellspring of heat to liquefy the metallic substrate and concurrent feeding of the clay particles (as powder) in the liquid surface. This is the fabrication of a surface layer of particulate (ceramics like WC, TiC, SiC, ZrO_2 or Al_2O_3) reinforced metal matrix (any of the feasible metal like Ni, Fe, etc) composites on metallic materials.

A powder mixture of Ni alloy, titanium (99.7% purity) and crystalline graphite (99.5% purity) was used as the coating alloy on substrate of 5CrMnMo steel which increased its hardness to 1250 $HV_{0.2}$

Laser coating of 30 vol.% TiC particulates and 70 vol.% Ni-alloy powders on 1045 steel treated under a power of 1000W produces a clad of hardness $HV_{0.2}$=1300.

2.3 TIG cladding on AISI 304 Stainless steel

AISI 304 stainless steel has the extraordinary mixes of prevalent mechanical properties and aqueous erosion resistance and subsequently utilized as basic materials [8]. But due to its low hardness (200 HV), its tribological properties are very poor [9]. The addition of carbon can increase the hardness of stainless steel simultaneously decreasing its ductility. Also heat treatment of stainless steel for increasing its hardenability is not profitable because, heat treatment causes the carbon to combine with the Cr in steel to form chromium carbide which has the formula $Cr_{23}C_6$. This compound forms along the grain boundaries and robs the regions along the grain boundaries of Cr.

Cheng et al. studied the dispersion of ceramic particles (WC, CrC, SiC, TiC, CrB and CrO) on austenitic stainless steel UNS S31603 using a laser surfacing technique. The powders were pasted on the surface of UNS S31603 first, followed by surface melting using a high-power laser.

2.4 Different research works to improve surface properties of materials

The micro-hardness of the surface was improved to 250-350 VHN as compared to 220 VHN of the AISI 304 stainless steel substrate when it is laser treated with TiB_2 as coating and observed a significant improvement in wear resistance property. The mechanism of wear was found to be a combination of adhesive and abrasive in as-received stainless steel. However, it was predominantly abrasive for laser composite surfaced stainless steel.

Direct laser cladding of SiC dispersed AISI 304 stainless steel produced defect free and homogeneous microstructure which consists of partially dissolved SiC in grain refined austenite. The hardness increased from 155VHN to 250-340 VHN.

TiC exhibits a very high melting point and thermal stability, high hardness and excellent wear resistance, low coefficient of friction and high electrical and thermal conductivities. Because of its high melting point, TiC is a promising material to be used as first wall material in fusion reactors. Hard TiC ceramics are well known for combining a number of special properties that have made them of particular interest for a wide variety of applications-they are used as wear resistant coating for cutting tools and inserts and as diffusion barriers in semi-conductor technology.

Laser alloying of AISI 1045 steel with TiC powder fed by the dynamic blowing method was carried out. By changing the laser power, scan speed and feed rate values, the depositions properties were studied. Optimum parameters significantly increased the surface hardness, and some dissolution of TiC in the molten Fe produced a small fraction of TiC dendrites upon re-solidification of the coating.

Using Submerged Arc Welding (SAW) for alloying powder mixtures of ferro-chrome and stainless steel Fe-Cr-C composite was prepared that exhibited phenomenal wear and abrasion resistance properties along with improved hardness. Microstructural examination of produced samples showed the formation of carbides of different morphologies which were best interpreted as microstructures of undercooled alloys.

Using GTAW (Gas Tungsten Arc Welding) process a multicomponent alloy (Al0.5–Fe2–Co–Ni–Cr–Mo–Si) cladding was prepared on a low-carbon steel substrate. After examining under FESEM, XRD, EDS the result showed the presence of FeMoSi phase and a BCC phase in the dendritic and interdendritic regions, respectively. The resulting alloy had a wear resistance of the cladding layer four times that of the substrate. The improvement could be attributed to the high hardness of the dendritic FeMoSi phase and nanoscale precipitation in the interdendritic region.

Multi-component alloy filler method and the tungsten inert gas (TIG) cladding process were used to fabricate Fe–Co–Cr–Ni–Mox to study the microstructure and wear properties of the claddings. When Mo was absent, the claddings formed face-centered-cubic (FCC) solid-solution phase. With the increase in Mo concentration, the claddings comprised not only the primary FCC phase but also a phase with eutectic mixture of the FCC phase and σ phase. The microhardness of the claddings increased from 210 to 465 HV upon the addition of Mo due to the formation of the σ phase. Claddings with higher microhardness showed better wear performance due to precipitation strength and solid solution strength.

3.1 Problem definition and objective of the present work

From the literature review it is clear that TiC-Ni coating by TIG cladding strengthens the surface properties like hardness and wear resistance of various engineering materials. However, very little work related to TiC-Ni coating on AISI 304 steel have been done by TIG cladding to improve its surface properties. In the present work TiC-Ni coating has been developed on AISI 304 steel by TIG cladding and effect of different process parameters have been studied.

Objective of the present work are as follows

- To produce a TiC-Ni metal matrix composite (MMC) on AISI 304 stainless steel to improve the hardness and wear resistance.
- To study the microstructure of TiC-Ni MMC.
- To find the hardness values of the MMC so formed and compare it with constituent stainless steel.
- To study the effect of various process parameters i.e. current and scan speed on hardness value and micro structure of the developed TiC-Ni coating.

4.1 Materials and Equipments used

The following materials were used for developing the TIG cladding and studying the microstructure, hardness and other properties of TiC-Ni coating so obtained.

- Substrate-AISI 304 stainless steel (50mmx100mmx8mm)

AISI304 stainless steel

Stainless steel of type 304 whose composition is mentioned in table 3 is the most widely used stainless steel.

AISI 304 steel has phenomenal corrosion resistance in a wide variety of environments and when in contact with diverse destructive corrosive media. It has a great imperviousness to oxidation. AISI 304 stainless steel cannot be hardened by heat treatment. Only solution treatment can be done by rapid cooling after heating to 1010-1120°C. The average physical properties of AISI 304 stainless steel is shown in table 4.

AISI 304 stainless steel is typically used in:

· Chemical equipment
· Coal hopper linings
· Cooking equipment
· Food processing equipment
· Hospital surgical equipment
· Hypodermic needles
· Nuclear vessels
· Sanitary feting valves
· Beer kegs
· Cutlery and flatware
· Architectural paneling
· Brewery, dairy, food and pharmaceutical production equipment
· Springs, nuts, bolts and screws

Table 3: Stainless steel composition (AISI304)

Fe	C	Si	Mn	P	S	Ni	Cr	Mo
Balance	0.08%	1%	2%	0.045%	0.031%	8.0-10.5%	18-20%	0.224%

Table 4: Physical Properties of AISI 304 stainless steel

Property	**Value**
Density	8.00 g/cm^3
Melting Point	1400-1455°C
Modulus of Elasticity	193-200GPa
Thermal Conductivity	16.2 W/m.K at 0-100°C
Thermal Expansion	17.2x10-6 /K at 100°C
Tensile strength (MPa)	505(ultimate)
Compression Strength (MPa)	210
Hardness Vickers(HV)	129

- Coating used- TiC-Ni powder (size- 44μm)

Titanium carbide

TiC is a hard refractory ceramic material similar to that of tungsten carbide whose physical properties are said in table 5. It has the appearance of black powder with face centered cubic crystal (FCC) structure. Commercially widely used in tool bits. Primarily used for cermet preparation.

Table 5: .Physical properties of TiC

Density (gm/cc)	Melting point (^{O}C)	Modulus of elasticity at room temperature (GPa)	Thermal Conductivity at room temperature (W/m-K)
4.92	3067	439	17.14-30.93

- **Nickel**
  Nickel is extensively alloyed with iron, tungsten carbide and chromium to produce stainless steel. Its high electrical conductivity finds application in electronic sector. It is also used as corrosion resistant material.

Table 6: .Physical properties of Ni

Density (gm/cc)	Melting point (^{O}C)	Modulus of elasticity`(GPa)	Thermal conductivity at room temperature (W/m-K)
8.902	1453	200	0.909

TIG WELDING SETUP

The TIG welding setup mostly consists of a power source, tungsten electrode, a TIG torch, shielding gas cylinder and a TIG unit with incorporated control systems. The use of filler rod is optional in this form of welding. But, in welding thicker sections, addition of filler metal is necessary. To generate an electric arc, a high frequency similar to tesla coil provides an electric spark. This spark acts as a conductive medium for the electrons to flow with the shielding gas and welding current is generated. This welding current leads to initiation of an arc whose stability will depend upon the amount of current and the distance between the electrode and the work piece. A brief description of the main components follows:

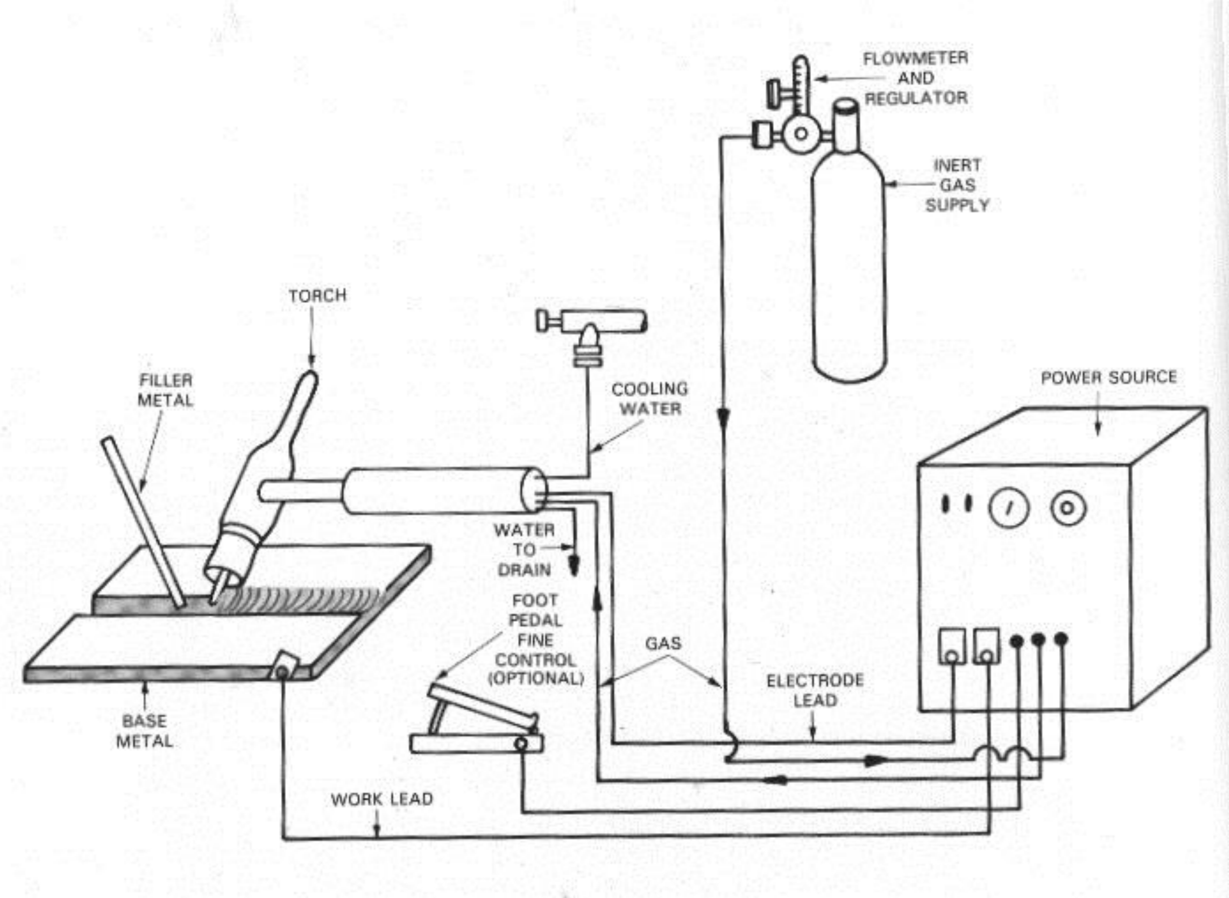

Fig-1: TIG Welding Setup [Ref.: office.pickproducts.com.au]

TIG torch: Its main purpose is to carry shielding gas and welding current. At the centre of the torch, tungsten electrode is attached. The inert gas is supplied to the welding zone through an annular path surrounding the atmosphere around the weld puddle. The torch handle is fitted with switch to turn the welding current and shielding gas on and off. They can be used for both manual and automatic welding operations with a basic difference in their designs. The size of the welding nozzle is decided by the amount of the shielded area required. The torch has connections to power supply and the shielding gas cylinder, and in some cases, it is also connected to water supply which acts as a coolant.

Gas cylinder: It provides continuous supply of argon or helium gas and also acts as a container for them. These gases act as shielding gases and are supplied with the help of cables connected to the torch. They protect the weld pool from atmospheric contamination. As the shielding gas is transparent, operator can clearly observe the weld.

Power sources: These are always of constant current type which means that the current will remain constant irrespective of the changes in arc distance or voltage. Thus, the heat generation will also remain relatively constant. Both DC and AC supplies can be used for TIG welding.

Electrode: Electrode initiates the arc acting as the element for closing the electrical circuit. It should be clean and free from contamination. Here, the electrode used is mostly made up of tungsten as it possesses high melting point and high electrical conductivity. The oxidation of electrode occurs to form tungsten oxide when electrode is allowed to cool in atmosphere after welding. It causes quick consumption of electrode by loss of metal in electrode tip. So, supply of gas should be continued for some time after welding to cool it properly.

Filler rod: It provides the filler material to be inserted in gap for welding. It is mostly made up of mild steel or stainless steel. The size of filler rod depends on base metal thickness. It is generally 1.5-3 mm in diameter.

Portable Moving Tractor (PMT)

It is an electrically worked machine which has a cubical body having four wheels associated with it. The PMT is named Messer Portacut and it accompanies a rail track of 1200 mm long. It moves straightly on this predetermined track with consistent velocity. Its capacities are controlled by forward/off/opposite switch, grip lever and rate conformity handle. Light can be fitted to the machine with screws and nuts so it can move straightly with the same speed as that of the machine. The handle gave on the machine decides the pace. By pivoting it, speed can be expanded or diminished. The pace change handle comprises of 10 velocity levels. The level 1 compares to the slowest speed while the level 10 relates to the most astounding rate. The best possible welding rate will between the level 2 to 5. Additionally, heading of movement can likewise be changed (forward or in reverse) by another lever sort switch gave at the edge of the machine which can be moved left or right. The rate of PMT can be fluctuated by of welding pace, measure of required and rate of deposition. The torch tip and filler rod are to be adjusted at exceptionally exact point so that legitimate heating of metal happens bringing about uniform globule size.

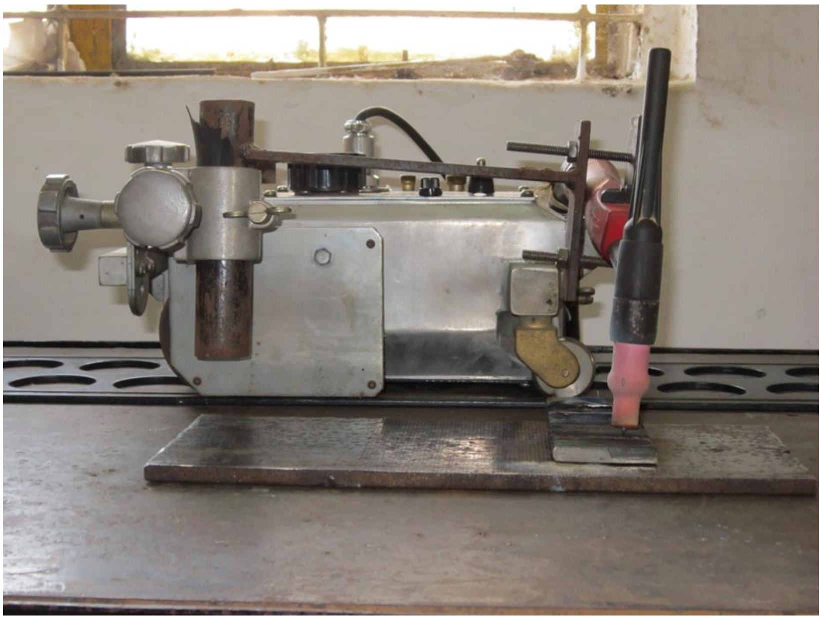

Fig 2: Portable Moving Tractor (PMT)

4.2 Experimental procedure

Experiment can be divided into four stages, namely

1. Preparation of coating on the substrate AISI 304 Stainless Steel
2. Polishing operation
3. Analysis of the coating on the substrate

- **Preparation of coating on the substrate**

Firstly the AISI 304 substrate of dimensions 100mmx50mmx8mm was cleaned on the countenances to get obliged surface completion. At that point the substrate was cleaned with ethyl alcohol and acetone [$(CH3)_2(CO)$] individually to uproot any undesirable particles, dust or burr. Coating powder which was TiC -Ni in equal proportion is blended with a binder. The binder utilized as a part of this case was dendrite which is a semi-strong, was condensed by utilizing CH3)2CO. The arrangement of TiC-Ni, $(CH3)_2(CO)$ and dendrite was continually mixed with the assistance of a glass rod until the arrangement gets to be homogeneous. The homogeneous arrangement so framed was spread over the substrate to get a uniform thickness on the AISI 304 substrate. The green coating was permitted to dry in normal barometrical condition until it is dried.

Fig .3: TIG cladding on AISI 304 stainless steel with different parameter combination

The initial sample thicknesses and its average value is shown in the table no 8 and 9

Table no 8: Thickness of plate before and after coating of TiC-Ni

Measurement no	1	2	3	4	5	6	7	8	Average thickness
Initial thickness (mm)	7.09	7.09	7.08	7.09	7.10	7.11	7.09	7.08	7.09
Final thickness (mm)	7.49	7.40	7.47	7.47	7.35	7.36	7.41	7.51	7.43

So average thickness of the coating is = average thickness of the sample with coating - average thickness of the sample without coating

Which is, 7.43 mm -7.09 mm =0.34 mm

Initial weight of beaker = 35.938 gm

Weight of TiC powder = 5.02 gm

Weight of Ni powder = 0.944 gm

After that it was scanned at various current and speed condition by the semi-automatic portable moving tractor (PAT).The different scan speed and current conditions have been tabulated in the table no 10.

Table no10: process parameters

Experiment No.	I_p (amp)	Scan speed (mm/sec)
1	40	5.3
2	40	6.5
3	50	5.3
4	50	6.5
5	60	5.3
6	60	6.5
7	80	5.3
8	80	6.5

After the coating is prepared then it was cut in wire-cut EDM. The cut pieces are shown in the figure no.

- **Polishing:** The cut pieces were polished in the polishing machine with the help of P-220, P-600 and P-1200. P-1200 produces super finished product. After that diamond finishing operation was done to get mirror finishing touch. The products of mirror finishing operation are shown in the figures no.

- **Analysis of the coating on the substrate**

  Desired properties of the TIG cladded surface such as Hardness, wear, micro-structure are measured using different measuring instruments available in the institute like **Vickers Microhardness tester, Optical microscope, FESEM.**

4.3 Characterization of TIG treated samples

FESEM analysis

FESEM is used to study the detailed microstructure of the laser treated TiC-Ni coating on AISI 304 stainless steel. For this the samples was cut across the length perpendicular to the scan direction in such a way that the cross section of the clad was exposed. The cross segment range was cleaned with coarse emery paper to evacuate the unpleasant territory got in the wake of cutting of the specimen. At those points, it was cleaned with fine emery papers. Then it was polished with fine emery papers of grades p-220, p-600, p-1200, and diamond finishing (in the increasing order of fineness) respectively. Finally the sample was cleaned with acetone before testing it under FESEM. The micrographs have been taken in the BSE (back scattered electron emission) mode.

Optical microscopy analysis

Optical or light microscopy involves passing visible light transmitted through or reflected from the sample through a single or multiple lenses to allow a magnified view of the sample. The resulting image can be detected directly by the eye, imaged on a photographic plate or captured digitally.

The single lens with its attachments, or the system of lenses and imaging equipment, along with the appropriate lighting equipment, sample stage and support, makes up the basic light microscope.

Micro hardness analysis

Microhardness of the developed coating was measured under Leco microhardness tester (company -LM248AT) with 50gf indenting force and dwell time of 10s. Normal hardness of every track having individual arrangement of TIG cladding handling parameters, was found by taking 8-10 hardness estimation.

5.1 Surface roughness measurement

The surface produced by different current and scan speed conditions are analyzed under the profilometer to measure the average surface roughness (R_a) or center line average (CLA) shown in (Fig 15 and Fig 16). The following table shows the readings of profilmeter with a range of 0.2µm and least count (L_e) = 0.8µm. For every current and scan speed condition three readings were taken and are tabulated in the table no 11.

Table no 11: roughness value against process parameters

I_P(amp)	Scan speed (mm/sec)	roughness (R_a) (µm)	Average R_a (µm)
40	5.3	18.0, 9.0, 11.6	12.87
40	6.5	10.2, 11.4, 8.0	9.87
50	5.3	17, 7.2, 6.4	10.21
50	6.5	10.4, 10.6, 6.2	9.07
60	5.3	8.6, 7.0, 6.8	7.47
60	6.5	6.4, 2.8, 6.2	5.13
80	5.3	2.2, 4.0, 7.0	4.40
80	6.5	4.6, 1.8, 2.6	3.00

From the above when the current is increased the average value of R_a is decreased because with increase in current the heat available is more and uniform mixing of TiC-Ni coating on AISI 304 stainless steel occurs resulting in homogeneous structure.

The graph depicting the variation of average surface roughness R_a and current with different scan speed is shown in the figure no

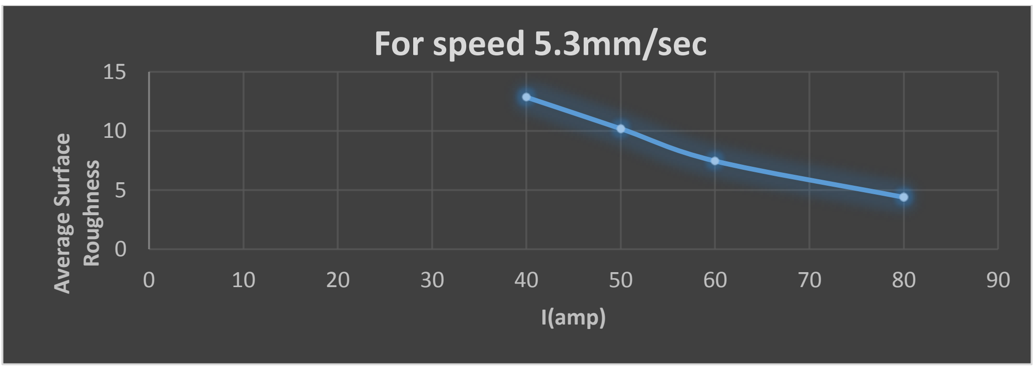

Fig.4: Graph between R_a and current at 5.3 mm/s

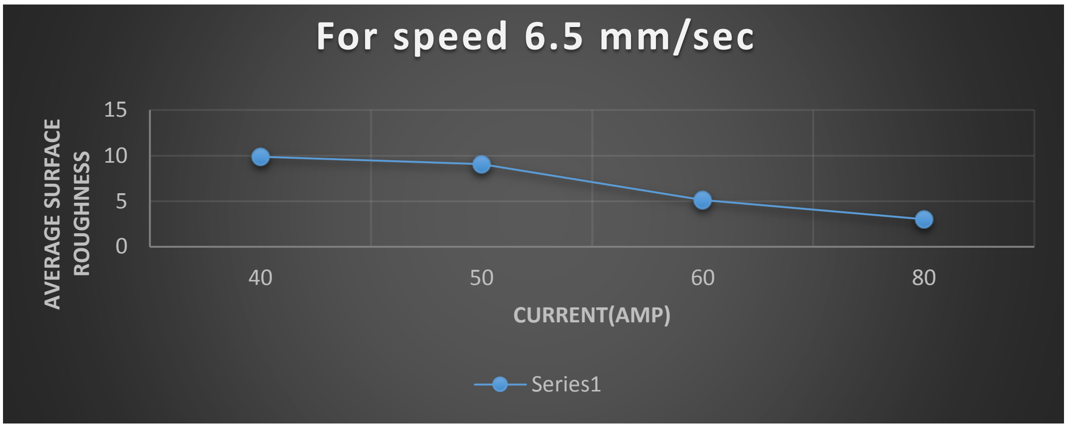

Fig. 5: Graph between Ra and current at 6.5 mm/s

From the graph it is clear that in both the cases the average surface roughness decreases with the increase in current at a constant scan speed, this is because with increase in current heat available is more that results in uniform melting of weld bead producing less waviness that in turn results less more uniform surface finish.

5.2 Optical microscopy analysis

Fig .6: The magnified microscopic image of the cross section of the TIG cladded AISI 304 stainless steel processed with 40 amp and scan speed of 5.3 mm/s

Fig .7: The magnified microscopic image of the cross section of the TIG cladded AISI 304 stainless steel processed with 40 amp and scan speed of 6.5 mm/s

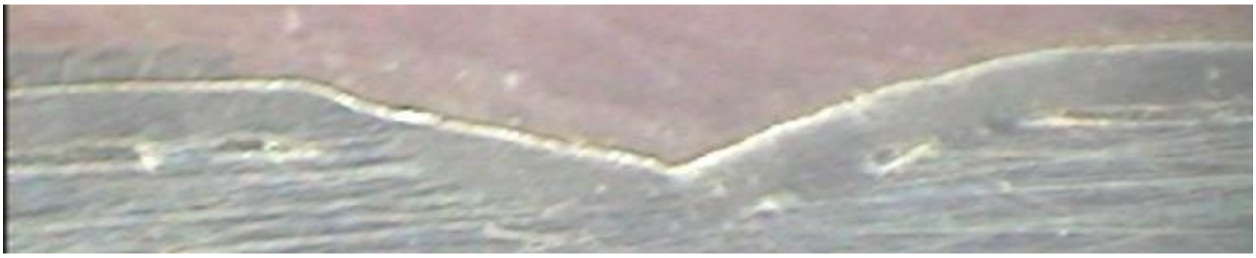

Fig .8: The magnified microscopic image of the cross section of the TIG cladded AISI 304 stainless steel processed with 50 amp and scan speed of 5.3 mm/s

Fig .9: The magnified microscopic image of the cross section of the TIG cladded AISI 304 stainless steel processed with 50 amp and scan speed of 6.5 mm/s

Fig .10: The magnified microscopic image of the cross section of the TIG cladded AISI 304 stainless steel processed with 60 amp and scan speed of 5.3 mm/s

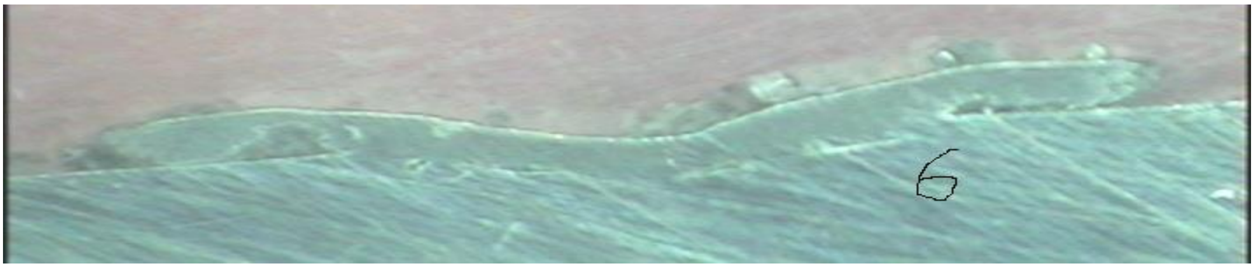

Fig .11: The magnified microscopic image of the cross section of the TIG cladded AISI 304 stainless steel processed with 60 amp and scan speed of 6.5 mm/s

Fig .12: The magnified microscopic image of the cross section of the TIG cladded AISI 304 stainless steel processed with 80 amp and scan speed of 5.3 mm/s

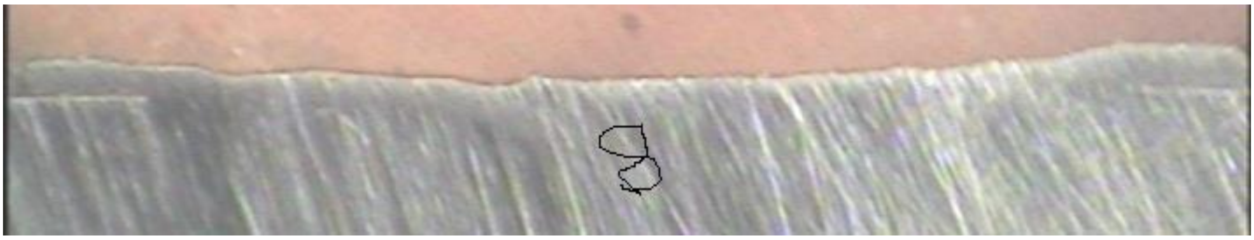

Fig .13: The magnified FESEM image of the cross section of the TIG cladded AISI 304 stainless steel processed with 80 amp and scan speed of 6.5 mm/s

5.3 Microstructure analysis under FESEM

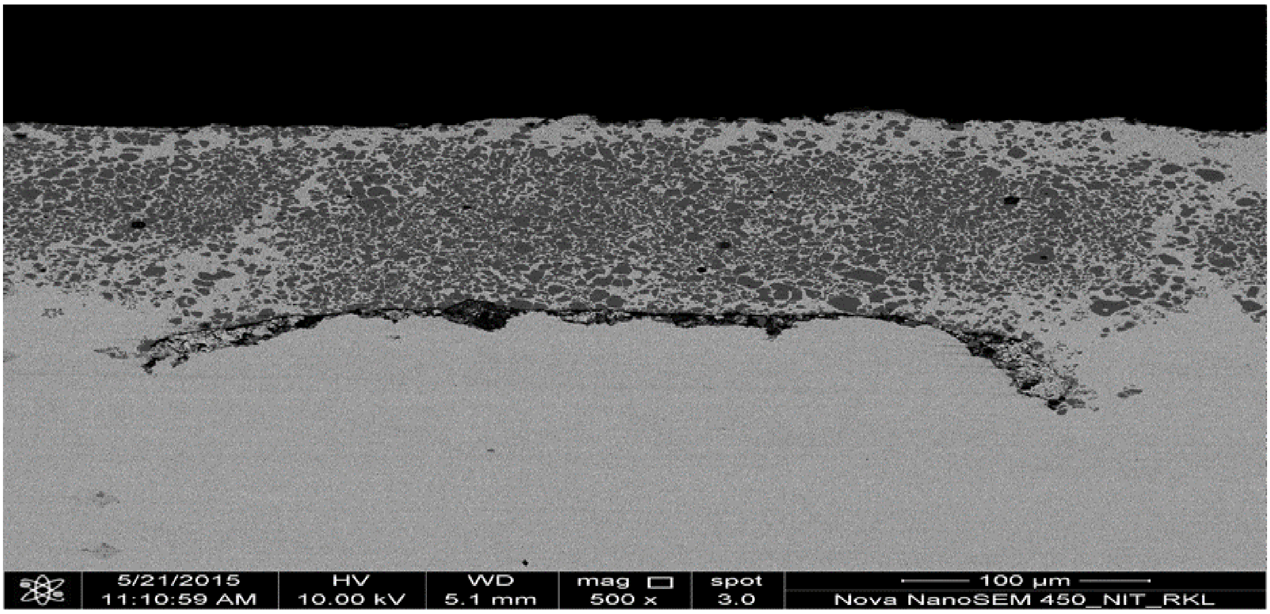

Fig. 14: The magnified FESEM image of the cross section of the TIG cladded AISI 304 stainless steel processed with 40 amp and scan speed of 5.3mm/s.

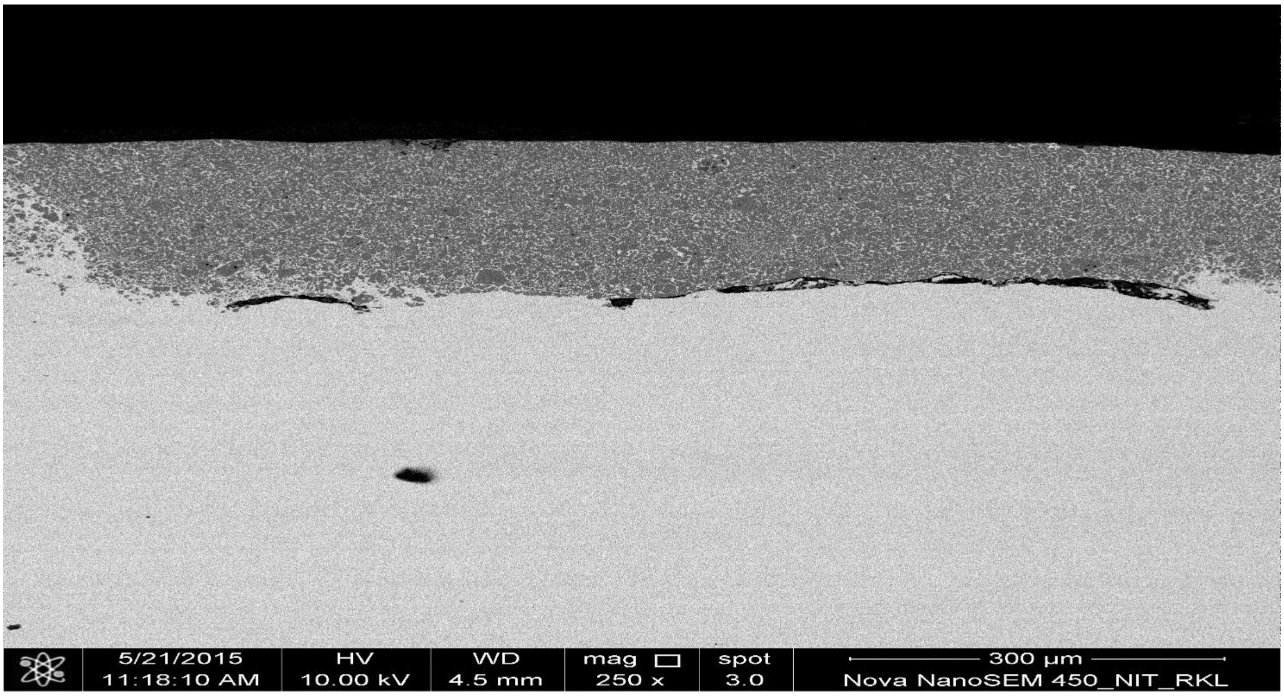

Fig. 15 The magnified FESEM image of the cross section of the TIG cladded AISI 304 stainless steel processed with 40 amp and scan speed of 6.5 mm/s

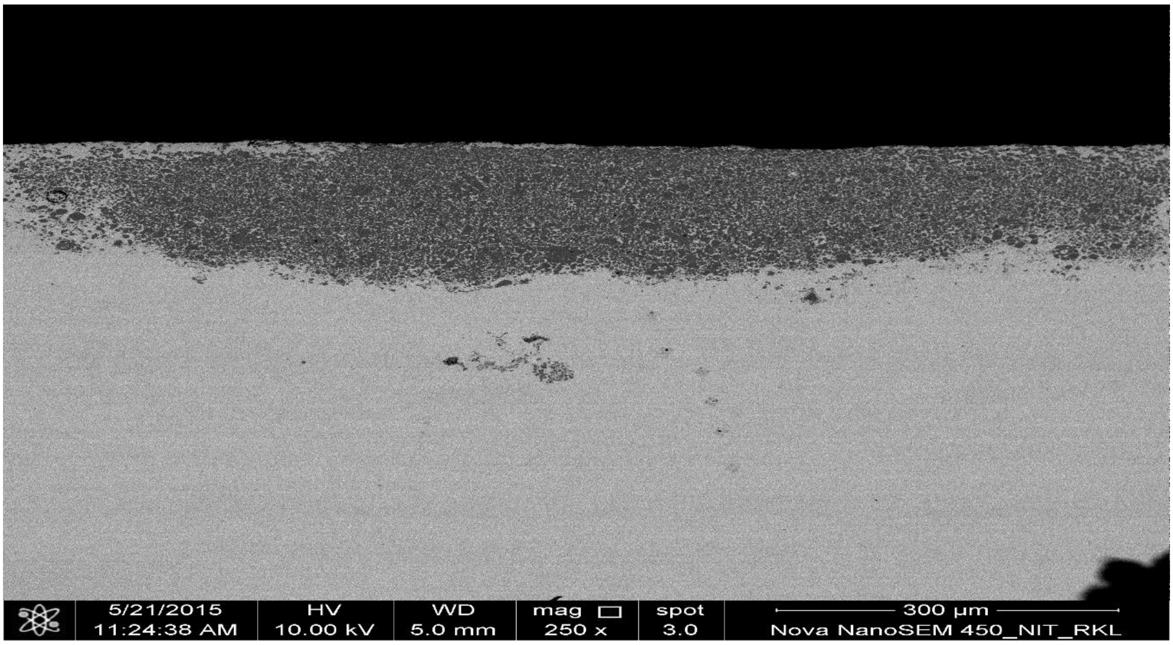

Fig. 16: The magnified FESEM image of the cross section of the TIG cladded AISI 304 stainless steel processed with 50 amp and scan speed of 5.3 mm/s

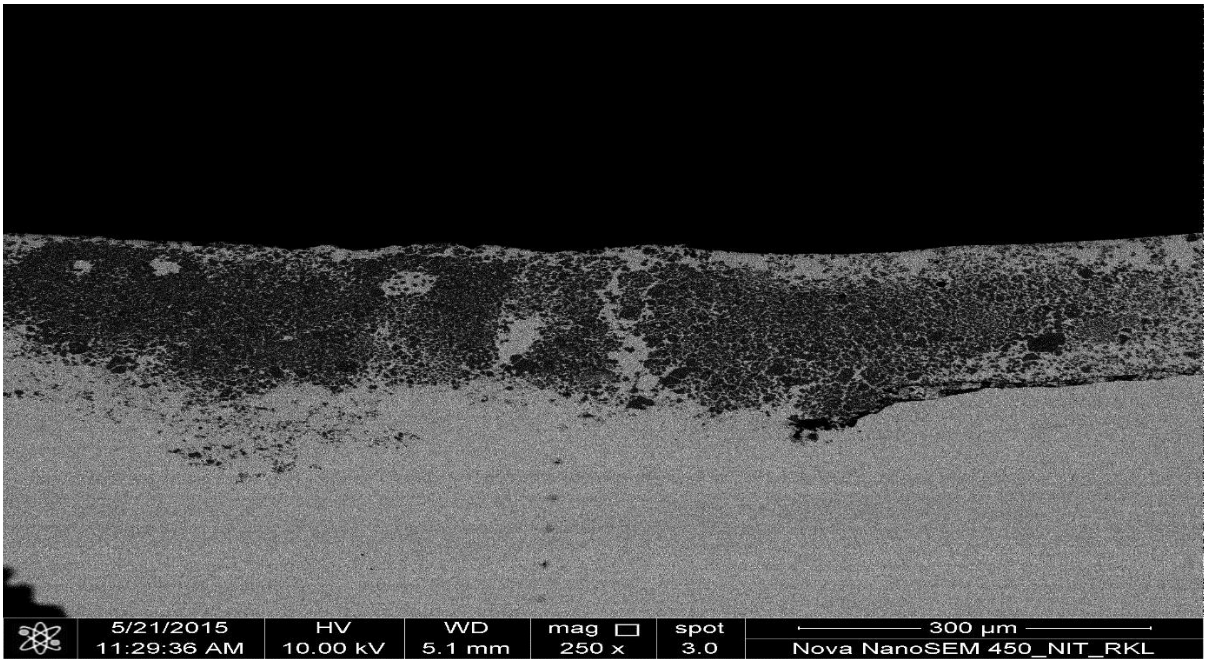

Fig. 17: The magnified FESEM image of the cross section of the TIG cladded AISI 304 stainless steel processed with 50 amp and scan speed of 6.5 mm

Figure 17 to 21 show the top view of TIG cladding done on AISI 304 stainless steel substrate by using TiC-Ni as coating powder. In the FESEM images the dark region shows the TiC-Ni and the grey region is the substrate. Thus we can say that the type of coatings and the coating thickness obtained vary with changes in process parameters.

5.4 Micro-hardness measurement and effect of process parameters on hardness

5.3.1. Effect of TIG scan speed on hardness

To find the effect of TIG process parameters on microhardness of the coating obtained, a plot between microhardness measured in HV (Vickers hardness) (load taken 50gm) vs distance (µm) was drawn.

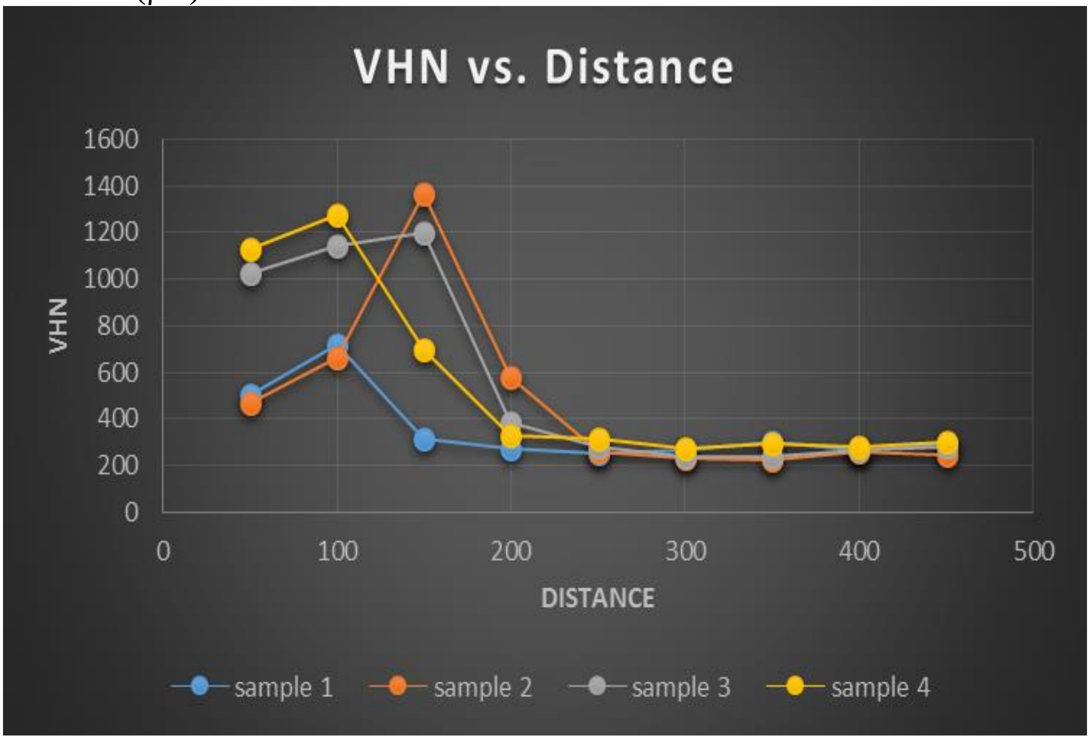

Fig. 18: graph between VHN vs, distance in µm from top surface in µm

From the graph it is clear that with increasing current heat available is more for uniform melting of the coating resulting more hardness. With further increase in distance hardness decreases.

6.1 Conclusions

- From the above experiment we can come to the conclusion that TiC-Ni coating has been successfully developed on AISI 304 stainless steel substrate.
- Using TiC-Ni as coating material, increases the surface properties of the stainless steel like its hardness, wear resistance without actually affecting its bulk mechanical properties.
- We can also conclude that the surface properties are affected by the TIG cladding process parameters like current, scan speed etc.
- From the microstructure analysis we can conclude that at low values of scan speed and current a thick coating of TiC-Ni is non-uniformly distributed over the TIG cladded tracks, thus the surface finish produced is poor. And at higher values of scan speed and current conditions a MMC type of coating is obtained in which TiC-Ni is dispersed over the substrate uniformly producing less waviness.
- It was found that hardness value lie in the range of 250-1300 $HV_{0.05}$ depending on process parameters.
- When effect of laser scan speed on hardness value was studied no peculiar relation has been observed.
- From the experimental results it has been observed that Hardness value of the developed TiC-Ni coating increases with increasing current keeping scan speed constant.
- It has also been observed that Hardness value of the developed TiC-Ni coating, decreases with increasing distance from top surface.

6.2 Future scope

- Study the tribological behaviour (wear resistance, coefficient of friction) of the developed TiC-Ni coating.
- Development of in-situ laser cladding process for exhibiting benefits of production of coating powder within the laser system itself and using TiC-Ni as reinforcement and along with it some other metals which serve as matrix and improve the surface properties further.

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