Surface modification of Ni-hard 4 cast iron with titanium using GTA heat source

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Abstract

Ni-hard 4 cast iron has high strength and wear resistance material used in pipe fittings, concrete mixture, etc. In this study, improve the surface property like hardness, wear resistance of Ni-hard 4 cast iron and adding alloying element like Titanium grade 2 (0.6 mm) sheet on the surface using Gas Tungsten Arc as heat source. The hardness was taken at the base and modified area and it is increased from 597.5 HV to 1435 HV. Wear rate was found to be 4.7 for base and 0.15 for modified layer. The wear resistance is improved because of the formation of titanium carbide hard phase in the modified layer. The titanium carbide phase is formed and it was observed by XRD analysis. In the elemental composition analysis the presence of titanium 10 wt% was observed in the modified area.

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Selection and/or Peer-review under responsibility of International Conference on Advances in Materials and Manufacturing Applications [IConAMMA 2018].

Keywords: Ni-hard 4, GTA, Titanium, Hardness, Wear rate

1. Introduction

The cast iron was used in the field of mining, Minerals and Iron processing. Ni-hard 4 cast iron was a high strength material with the alloying element of Nickel and chromium. Ni-hard 4 cast iron as a category of white cast iron and it has an extreme abrasion resistance and fracture resistance compared to the cast iron category of Ni hard 1 and Ni-hard 2 materials. The wt.% of Nickel and Chromium has decided to the grade 4 of this material. The carbon content of this material is compromised between Abrasion resistance and toughness.
The experiment on Ni-hard 4 cast iron is conducted and adding alloying element like titanium and vanadium atoms has been mixing with the carbon content to form titanium carbide and vanadium carbide. These formations of the carbide contain high amount of strength and the properties was huge improved. Mithun et al [1] conducted the experiment on steels with variation of carbon content during the Wt.% of 0.2, 0.5 and 1.1 using Titanium sheet on the surface of the material and it is modified using GTA. The modified area hardness is increased because of the titanium particle is dispersed on to the surface area and wear resistance is improved. Sandeep Nair et al [2] reported that the Al-bronze alloy with the variation of Ni content and surface of the material is modified using GTA heat source. The phase has been formed on the solidification area. The hardness and wear resistance was improved due to the formation of the phase like AlNi3. Krishna Kumar et al [3] conducted the experiment on 6h heat treated AISI 304 stainless steel. The titanium sheet with the thickness of 0.3mm is used on the surface of the material and it is modified using GTA heat source. The properties are improved in the modified area. Vijay Narayanan et al [4] conducted an experiment on AISI 304 stainless steel with Titanium sheet on the surface it is modified using GTA heat source. The presence of Ni3Ti phase on the modified layer the hardness is improved from 263HV to 2098HV. Mohammadnezhad et al [5] investigating the effect of vanadium concentration as a reinforcement to the Ni-hard 4 cast iron. The maximum vanadium concentration 2 Wt.% was increasing the hardness from 22% compared to the substrate material. The properties were increased because of the formation of vanadium carbide and chromium carbide. Labudovic et al [6] investigated the Ti-6Al-4V alloy is surface modified using GTA under nitrogen atmosphere. The modified area properties were improved because of the formation of Titanium nitrides. Masoud Bahrami Alamdaulo et al [7] conducted an experiment on Ni-hard 4 cast iron with Titanium reinforcement. The titanium 1.3 wt.% attains the maximum hardness of 963HV and the wear resistance was improved. The formation of titanium carbide and chromium carbide formation the hardness and the wear resistance was improved. Kassim, Al-rubie and Michael Pohl [8] investigated the heat treatment and two body abrasion of Ni-hard 4 cast iron. It was carried out using destabilization and sub critical heat treatment at 820C for 4h and 300C to 550C for 4h. The result showed that the greater abrasion resistance is increased under destabilization process and abrasion resistance decreased under tempering process. Blagoj Lj, Rizov [9] reported that the Ni-hard cast iron sample subjected to annealing (heat treatment) process. The Ni-hard 2 sample is treated at 480C for 4h and Ni-hard 4 sample is treated at 790C for 4-8h. The Ni-hard 4 sample properties are 22.5% improved compared to the cast sample and Ni-hard 2 cast and heat treated sample. Prashanth et al [10] investigated the AA 7075 alloy with TiC powder as an alloying element added on the surface using Poly vinyl alcohol as a resin and laying over the substrate. The surface is modified using GTA heat source. The hardness is increased to 33% and wear resistance was improved because of TIC particles is dispersed in the modified area. Dyuti et al [11] conducted an experiment on plain carbon steels with a surface coating of Ti-Al powder. GTA heat source is used for modification process and the hardness was attains 900HV in the modified area. Essam and Hashan [12] conducted an experiment on graphite cast iron and modified using laser surfacing. The fusion zones were measured with the laser power between 700, 1000, and 1500W. The maximum hardness was found to be 1430HV at 700W laser power in the modified layer. Soner buyt oz and Yildrim [13] reported that the 64Cr-80Si-6.84C-26.84Fe hypereutectic alloy powder with PVA to form a binder and coated on the surface of the AISI 4340 steel. The surface area has been modified using GTA heat source. The wear resistance is improved because of the formation of M7C3 carbides. The works have been done on Ni-hard 4 cast iron with reinforcement like titanium, vanadium and heat treatment of this material. No study has been done with titanium sheet on surface alloying using GTA. In this present study investigates the Ni-hard 4 cast iron modified layer properties were compared with the substrate material.
2. Experimental Procedure

The induction furnace is used for making the Ni hard 4 cast iron within a melting point temperature between 1460 to 1500. Sand moulds are used for this casting. The chemical composition of Ni hard 4 cast iron is measured using optical emission spectroscopy. Titanium grade 2 (0.6mm) sheet is cut into the dimension of 150mm x 30mm x 30mm dimension and the sheet is fitted with a surface of Ni hard 4 cast iron.

The GTA parameters are shown in the Table 2. The specimen was mounted on the working table. The GTA torch was held stationary for all the experiments. Tungsten electrode of diameter 3mm using the linear manipulator. The specimen was placed such that the electrode lies above the specimen and its one end. Electrode holder holds the tungsten electrode. Shielding gas is used to protect the weld from the atmosphere. GTA has more efficiency than other heat sources.

The piece is subjected to wire cut process and slice and clean with acetone, polishing to measure hardness, wear rate and microstructure evaluation.

| Table – 1 Composition of base metal (Ni-H4Cl) |
|---------------------------------------------|
| Element | Cr  | Si  | Ni  | C  | Fe |
| Wt.%    | 11.25 | 1.103 | 5.022 | 2.52 | Bal |

| Table – 2 Gas Tungsten Arc processing parameter |
|-----------------------------------------------|
| Parameter          | Value | Value | Value | Units |
| Current            | 180   | 190   | 200   | A     |
| Electrode Diameter | 3     | 3     | 3     | mm    |
| Travel Speed       | 3     | 3     | 3     | mm/s  |
| Arc Length         | 4     | 4     | 4     | mm    |
| Electrode Angle    | 180 (flat) | 180 (flat) | 180 (flat) | Degree |
| Argon Flow Rate    | 12    | 12    | 12    | L/min |

| Table – 3 Wear parameter (G99 standard) |
|----------------------------------------|
| Parameters                | Test values | Units |
| Speed                     | 425         | rpm   |
| Velocity                  | 2.5         | mm/s  |
| Track diameter            | 110         | mm    |
| Time                      | 10          | min   |
| Sliding distance          | 1500        | m     |
| Load applied              | 2           | kg    |
3. Results & Discussion

3.1. Effect of welding parameters

The Ni-hard 4 cast iron surface has been modified using GTA with different parameter varying with current. The melting point of titanium is 1600°C. At 180A current the solidification occurred and the fusion area was not in depth so that the titanium particles were dispersed in a top surface only. At 190A and 200A current the large fusion area has occurred and the titanium particles were dispersed into the 3mm region of the substrate material. The heat input calculation of this process is shown below. Table 4 shows the depth concentration of the process

Heat input calculation:
- Arc energy = voltage x current / Travel speed
- Heat input (HI) = 0.8 x Arc energy (J/mm)

| S.no | Depth of penetration | Heat input |
|------|----------------------|------------|
| 1    | ![Image](image1)     | 1015 J/mm (200A) |
| 2    | ![Image](image2)     | 978 J/mm (190A) |
| 3    | ![Image](image3)     | 820 J/mm (180A) |

3.2. Microstructure and SEM analysis

The microstructure of the base and the GTA modified layer was shown in Figure 1. and 2. The picture was observed and captured using the carl zesis microscope. The magnification of the microstructure was observed by 500x. The substrate material has eutectic carbides and M7C3 carbides were observed. On the surface modified region, the titanium particles were dispersed and the
dentritic grain structure is formed and able to identify the intermediate phase like titanium carbide and other stable carbide phase is formed. This Ni-hard 4 cast iron surface grain refinement was attributed due to the cooling rate that ensures heat input between the modified layer and the substrate.

Figure 1 microstructure of as cast Ni-hard 4 cast iron (500x)

Figure 2 microstructure of modified Ni-hard 4 cast iron (500x)

Figure 3. SEM micrograph of Ni-H4Cl
Figure 4. SEM micrograph of Ni-H4CI Modified layer 200A

Figure 5. SEM micrograph of Ni-H4CI Modified layer 190A

Figure 3. presents the SEM micro picture of Ni-hard 4 cast iron as in cast condition. It was observed that the retained austenite, Martensite layer, eutectic carbides and M7C3 carbides were observed under the magnification of 1000x [3]. Figure 4 and 5 showed the SEM micro picture of the modified area. It also shows that the hard particles of titanium carbide, iron carbide, chromium titanium particles are formed. The TiC phase and other phase are effectively hard particle phases. This is the huge reason behind the strength of the material in a modified layer which increases due to the presence of the hard particulates that were distributed. Also, Titanium got distributed as such in the modified region. This influences the surface alloying in the modified region.

3.3 EDS Elemental compound analysis
Figure 6 and 7 shows the elemental compound analysis (EDS) of the substrate material and the surface modified region. The experimental result shows the presence of Titanium element up to 10.21 wt.% in the modified region. The more amount of titanium particulates was distributed on the modified region. So the intermetallic compound like titanium carbide and chromium titanium, iron carbide hard particulates were formed. The presence of the hard phases was identified using the X-Ray Diffraction (XRD). Table – 4 shows the composition of the modified layer.
Table – 5  Elemental Composition of substrate

| Element | Cr  | Si  | Ni  | C  | Fe  |
|---------|-----|-----|-----|----|-----|
| Wt.%    | 10.95 | 1.103 | 4.87 | 2.96 | Bal |

Table – 6  Elemental Composition of the modified area (Ni-H4CI with tungsten)

| Element | Cr  | Si  | Ni  | C  | Ti  | Fe  |
|---------|-----|-----|-----|----|-----|-----|
| Wt.%    | 10.95 | 1.103 | 4.87 | 2.96 | 10.0 | Bal |

3.4 XRD analysis (phase identification)

The Titanium sheet modified layer treated with a GTA parameter of 200A phase analysis was carried using the XRD analysis equipment. From the Figure 8 showed the phase formation and phase identification of titanium modified Ni-hard 4 cast iron. The GTA modified layer shows the hard particles like the peaks of titanium carbide, chromium titanium, iron carbide in different areas in the fusion area. The hard phases, grain refinement and more intermetallic phases can be formed because of that reason. So the surface properties of the Ni-hard 4 cast iron was improved because of the formation of hard phases in the modified layer.
Figure 9. XRD analysis of modified layer

The Titanium sheet modified layer treated with a GTA parameter of 200A phase analysis was carried using the XRD analysis equipment. From the Figure 8 showed the phase formation and phase identification of titanium modified Ni-hard 4 cast iron. The GTA modified layer shows the hard particles like the peaks of titanium carbide, chromium titanium, iron carbide in different areas in the fusion area. The hard phases, grain refinement and more intermetallic phases can be formed because of that reason. So the surface properties of the Ni-hard 4 cast iron were improved because of the formation of hard phases in the modified layer.

3.5 Hardness Evaluation:

The hardness evaluation was carried out on the titanium alloyed modified region. The hardness was taken along the top surface of the modified layer. The average base material (Ni-hard 4) hardness was found to be 585HV. The average hardness of the modified layer on the top surface and it was shown in table. The hardness is increased because of grain refinement like dendritic structure and hard phases like Titanium carbide, iron carbide, and Chromium titanium were formed on the modified layer. The two times hardness increased in the modified layer compared to the base material. The hardness along the depth concentration as shown in Figure 10.

Table – 7 hardness measurement

| S.no | GTA parameter (Current) | Average modified Hardness HV |
|------|-------------------------|-----------------------------|
| 1    | 180A                    | 898                         |
| 2    | 190A                    | 1012                        |
| 3    | 200A                    | 1438                        |
3.6 Wear rate

The wear rate was calculated on a pin on disc wear testing machine. The wear rate was calculated on the base material and titanium modified layer (200A). Wear rate was found to be $4.1 \times 10^{-3} \text{ mm}^3/\text{m}$ for the base and $0.10 \times 10^{-3} \text{ mm}^3/\text{m}$ for the titanium modified layer. Comparing to the base material, the wear rate in the titanium modified layer decreases due to the reason of hard particles like titanium carbide was formed on the modified layer. Wear graph of base and modified layers shown in Figure 12.
4. Conclusion
The surface refining/alloying experiment were conducted on the Ni-hard 4 cast iron. Titanium sheet (0.6mm) as an alloying element was deposited on the surface area of the Substrate material. GTA as a heat source for surface alloying because it welds penetration and depth concentration is good and economically feasible. The properties are improved on the surface because of the surface alloying process. The following things are improved on the surface of Ni-hard 4 cast iron.

- The hardness is improved in the titanium modified layer compared to the substrate material.
- Wear rate is decreased on the modified layer compared to the substrate material and the titanium modified layer (200A) shows the excellent wear resistance.
- The properties are increased depending on the analysis of phase identification in XRD result the phase like titanium carbide and chromium titanium is formed at the modified layer was observed.
- The grain refinement and dendritic grains formed on the modified layer was observed.
- The hard particle like Tic and iron carbide are formed on the modified layer was observed by scanning electron microscope.

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