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An Investigation on the Hardness and Wear Rate of Surface Alloyed AISI304 Stainless Steel with Ti using GTA as Heat Source

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Abstract

Background: Stainless steels are mainly used where prevention of corrosion attack is the main criteria, but low surface hardness and high wear rate are key obstacles to extensive application. **Methods:** The surface alloying of AISI 304 stainless steel with titanium was carried out using the heat generated from the Gas Tungsten Arc (GTA). Experiments were conducted by varying the GTA parameters and the optimal parameter was determined. Composition of the surface alloyed layer was analysed using atomic emission spectrometer. The Ti alloyed surface layers were characterized using SEM imaging/EDAX analysis. **Findings:** Composition of the surface alloyed layer was analysed using atomic emission spectrometer and the results confirmed an increase in the Ti content on the surface layer when compared to the composition of the substrate. The EDAX analysis showed that intermetallic alloys are present in the Ti alloyed surface layers. The microhardness was measured using the Vickers microhardness testing machine and the hardness increased from 267.5 HV for the substrate to 2098 HV for the surface alloyed layer. The wear was measured using the pin-on-disk wear tester and the wear rate decreased from 14.78 x 10^{-4} mm^3/m for the substrate to 1.84 x 10^{-4} mm^3/m for the surface alloyed layer. The observation of the microstructure revealed that there is grain refinement in the Ti alloyed surface layer. **Applications:** The modified specimens can be used as medical implants, control rods in nuclear power plants, pump barrels petrochemical industry. This method can be used to improve the properties in specific area of a product.

Keywords: AISI304, GTA, Hardness, Microstructure, Surface Alloying, Ti, Wear Rate

1. Introduction

Stainless steels are mainly used where prevention of corrosion attack is the main criteria, but their poor surface hardness and high wear rate has been key obstacles to extensive application. Stainless steels have been extensively utilized in nuclear, aerospace and aeronautical, food processing, biomedical and maritime industry because of its high corrosion resistance. Typical products of stainless steel that are subjected to surface treatment processes are surgical instruments, tools and moulds, gears, screws, valves, pump parts, bearings, filters, orthopedic parts. Researchers are developing newer methods and processes to augment the surface properties of materials without affecting the bulk properties.

Surface Alloying Process (SAP) is a novel method to vary the surface properties of a metal or an alloy without affecting its bulk properties. Titanium boride powder was alloyed onto the top surface of the 18/8 stainless steel using laser as heat source. It improved the hardness and wear resistance of 18/8 stainless steel. The experiment successfully increased the surface hardness of stainless steel used from 220 HV to 350HV. There was a marginal improvement in the wear resistance of the alloy[1]. In a study to enhance the surface properties of AISI304 stainless steel, surface alloyed a coating of tungsten carbide, Ni and NiCr powder onto the surface of the stainless steel substrate using laser as a heat source. The hardness on the surface of the substrate increased drastically from 220HV to 1400HV. They have reported that the increase in hardness led to a significant increase in the wear resistance[2]. AISI420 martensitic stainless

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steel was subjected to High Current Pulsed Electron Beam in order to modify the surface. This caused the surface hardness of the AISI420 martensitic steel to improve from 240 HV to 350 HV[3]. Cr-CrB_2 powder was coated on SAE304 stainless steel and subjected it to laser treatment. The laser treatment caused the coating to alloy with the surface of the SAE304 stainless steel. This resulted in the enhancement of surface hardness from 200 HV to 1300HV which is attributed to formation of different intermediate phases[4]. The microstructure on the surface layer of AISI304 austenitic stainless steel was transformed from austenite to martensite by the process of plasma nitro carburizing. This transformation led to the increase in surface hardness from 387.5 HV for the substrate to 1765 HV for the surface layer[5]. Experiments were conducted to laser surface alloy molybdenum onto AISI304 stainless steel. Molybdenum was pre-deposited on the steel surface by plasma spraying. The hardness of the alloyed region was measured as 690 HV where the hardness for the unalloyed surface was 235 HV[6]. Stainless steel of AISI304 grade was plasma nitrided to augment its surface hardness. For specimens which were plasma nitride at a temperature of 460^{o}C, the surface hardness augmented positively from 240 HV to 1700 HV[7]. Stainless steel containing 18% Cr and 8% Ni was subjected to a plasma paste boronizing treatment in an effort to enhance the surface hardness. The paste used for the treatment was a mixture of 70 wt% Borax and 30 wt% Boron. The hardness of the surface of the stainless steel used improved from 180 HV to 1800HV[8]. SKD11 grade cold worked die steel substrate coated with WC-Co powder was subjected to electron beam irradiation in order to increase its surface hardness. The experiment proved to be successfully as the surface hardness increased to 1000 HV for the surface alloyed layer from 200 HV on the substrate surface[9]. AISI316 stainless steel was exposed to electron beam irradiation for surface alloying with copper in order to enhance the hardness and anti-wear property. The copper was pre-deposited as thin films. The authors reported an improvement in the surface hardness and the wear behaviour in the near surface layer noticeably[10]. High current pulsed electron beam irradiation was utilized for the purpose of surface treating steel of FV250B grade. The authors reported that a 33% decrease in weight loss was observed after exposing the FV250B steel to 25 HCPEB pulses[11]. 40CrNiMo7 steel was subjected to electron beam irradiation for the process of surface treatment. After the surface treatment was completed, the surface hardness improved from 273 HV to 553HV. It was also found that the wear rate reduced to one-third of the initial value[12]. Laser surface alloying technique was used to surface alloy H13 steel substrate with Fe – 5.94W – 5.08Mo – 1.94V – 4.5Cr – 0.9C powder which was simultaneously feed onto the surface of the H13 steel substrate. The authors stated that the hardness improved from 230 HV for the substrate to 791 HV for the surface alloyed region[13]. 9Cr18 stainless steel substrate was coated layers of a mixture of TiB_2 and graphite and applied a laser heat source to carry out the laser surface alloying process. The surface alloyed region had a surface hardness of 950 HV while the substrate exhibited a surface hardness of 310 HV. As a result of the increase in surface hardness, the wear resistance of the surface increased significantly[14]. Laser peening process was carried out without the use of protective coating on 17-4PH steel using Nd: YAG laser. The process yielded a positive result which was the increase of the surface hardness from 295 HV to 341 HV[15]. GTA heat source was utilized to surface alloy 1018 steel with FeCr, FeCrC and WC–FeCrC alloy powders which were pre-coated on the surface of 1018 steel. The hardness of the surface of 1018 alloy increased from 410 HV to 1300 HV after surface alloying with WC-FeCrC alloy powders. The increase in hardness resulted in the decrease in wear loss for the 1018 steel[16]. AISI8620 steel was surface alloyed with SiC and C powders using GTA as heat source. The hardness of the surface improved from 205 HV to 987 HV after the surface alloying process. The authors also reported that the wear rate of the surface decreased drastically because of the increase in hardness[17]. AISI1045 steel substrate was surface alloyed with preplaced FeTi powder using GTA as heat source. The shielding gas utilized for the process is a mix of argon and nitrogen. After the process was completed, the surface hardness increased appreciably from 220 HV for the substrate to 1102 HV[18]. TIG surface alloying process was utilized to surface alloy a substrate of AISI304 stainless steel with SiC particulates to develop an MMC surface on the substrate. The surface hardness increased from 210 HV for the substrate to 1210 HV for the surface alloyed region. The enhancement in hardness is credited to the development of hard hypereutectic structure on the surface[19]. In a study to identify the most suitable shielding gas for plasma welding, it was found that helium provides the highest peak temperature and flow velocity near the cathode than argon gas[20]. But in this study, argon was used as shielding considering the economical cost of argon.

When different surface alloying processes were compared, it was observed that GTA method is comparatively economical, consumes less time and was the least complex. Therefore in this paper, an effort was made in investigating the surface hardness and the wear rate of the Surface Alloyed Layer (SAL) obtained by SAP of AISI304 stainless steel substrate with grade2 titanium using GTA as heat source.

2. Experimental Setup

The AISI304 stainless steel square rod with a dimension of 150x30x30 mm was use as the substrate. The composition of the substrate was identified using atomic emission spectrometer. Grade2 Ti (99.2% purity) sheet of dimension 150x30x0.4 mm was the alloying material used. The substrate and the Ti sheets were polished with emery polishing sheets and cleaned with acetone to remove dirt, grease and oxides. After placing the Ti sheet on the substrate, the GTA heat source was applied in the length direction to create the SAL.Figure1 illustrates the GTA heat source set up used for the purpose of surface alloying.

Figure 1. GTA heat source setup.

Several experiments were conducted by varying the GTA parameters and an optimal parameter for surface alloying was identified. The parameters kept constant for the experiments were 2% thoriated tungsten electrode of diameter 2.4mm and argon flow rate of 12L/min. The optimal parameter for surface alloying process is listed in Table 1.The composition of the SAL was analysed using atomic emission spectrometer. The specimen was sliced, polished and an etchant consisting of 10ml hydrochloric acid, 10ml nitric acid and 10ml of acetic acid was used to etch the surface. SEM imaging and EDX analysis was used to characterize the SAL.

Microstructure of the SAL was observed using an inverted metallurgical microscope and the hardness was measured using Vickers microhardness testing machine. 100 gm was load applied by the indenter for 15 sec on the SAL to measure the microhardness. Pin-on-disc wear tester was used to conduct wear tests on the substrate and surface alloyed layer. G99 specification parameters as per ASTM standards were utilised for the tests. (track diameter: 110 mm, speed: 424 rpm, load: 20N, time: 600 sec).

Table 1. Optimal parameter for Surface alloying

Sl.	Parameters	Set 1	Set 2
1	Current (A)	200	200
2	Electrode Tip Angle (deg)	60	180
3	Welding speed (mm/sec)	2	2
4	Stand-off distance (mm)	4	4

3. Results and Discussions

3.1 Microstructure Analysis

The width of the SAL at the top surface was 9 mm and the depth was 6 mm. The austenitic microstructure with equiaxed grains and the characteristics annealing twins of the AISI304 stainless substrate before surface alloying is shown in Figure 2. Figure 3 shows the dentritic structure formation in the surface alloyed layer. It can also be noted from Figure 3 that the structure is highly refined.

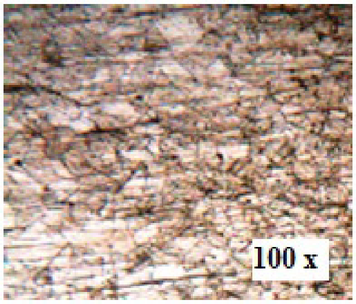

Figure 2. Microstructure of AISI304 stainless steel substrate.

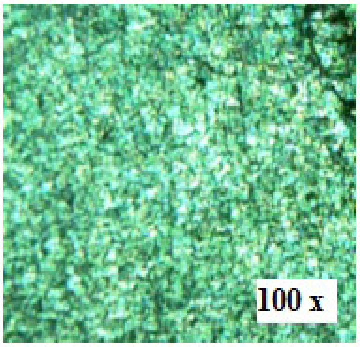

Figure 3. Microstructure of the Surface alloyed layer.

Figure 4 shows the presence of the intermetallic phase in the surface alloyed layer during SEM imaging. As per the Ni-Ti phase diagram, Ni_3Ti, NiTi, $NiTi_2$ are intermetallic phases that may be formed when Ni and Ti are alloyed together. EDAX analysis confirmed the presence of Ni_3Ti phase. The intermetallic phase Ni_3Ti was observed as lumps in the AISI304 stainless steel matrix.

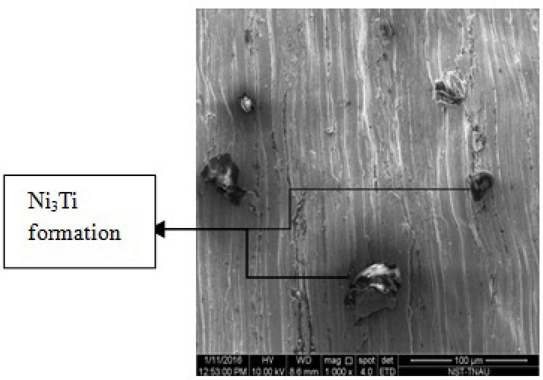

Figure 4. SEM image showing the presence of Ni_3Ti.

3.2 Composition Analysis

Atomic emission spectrometer was used to analyse the composition of the substrate and the SAL. Table 2 lists the composition of the substrate and Table 3 shows the composition of the SAL. It is understood that the percentage of Ti content has increased drastically from the substrate to the surface alloyed layer after the surface alloying process was carried out.

Table 2. Composition of AISI304 Stainless steel

Element	Cr	Ni	Ti	Mn	Mo	Fe
Wt %	18.7	8.4	0.05	1.6	0.5	Bal

Table 3. Composition of Surface alloyed layer

Element	Cr	Ni	Ti	Mn	Mo	Fe
Wt %	18.2	8.2	1.5	1.1	0.3	Bal

The composition of the intermetallic compound was identified by conducting spot EDAX analysis. The EDAX spectrum of the intermetallic compound Ni_3Ti which shows the peaks for Ni and Ti is given in Figure 5.

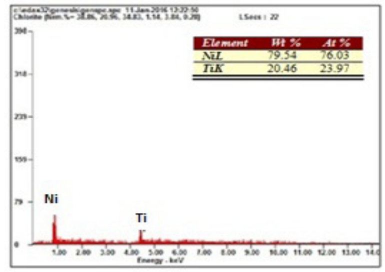

Figure 5. EDAX spectrum for Ni_3Ti.

3.3 Hardness

The hardness of the substrate was measured to be 267.5 HV. The hardness measured for the SAL was 2098 HV. This improvement in the hardness is credited to the presence of the hard intermetallic alloy Ni_3Ti and the grain refinement. There exists a gradient in the hardness when measured in the depth direction in the SAL. Figure 6 shows the hardness gradient present in the surface alloyed layer.

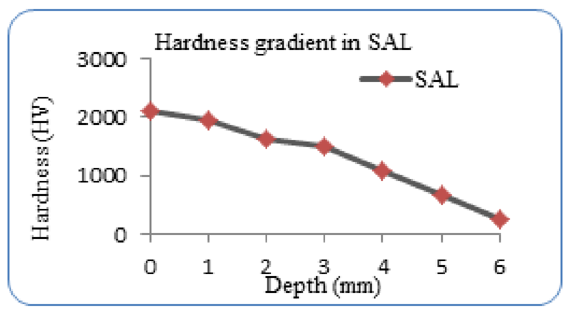

Figure 6. Hardness gradient (depth direction) in the SAL.

3.4 Hardness Data Comparison

Figure 7 shows the comparison of surface hardness data obtained from this study to that of the previous works reported in the literature. The substrate used in all the previous works compared is AISI304 stainless steel which is same as that used in this study. It is understood from the graph that the highest surface hardness and the highest increase of the surface hardness from the substrate to the SAL is also in the present study. This increase is credited to the presence of intermetallics and the finely refined grains in the SAL due to the rapid cooling associated with GTA surface alloying process.

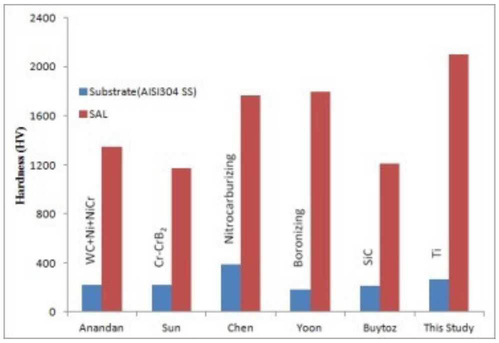

Figure 7. Hardness data comparison of different surface alloying process with this study.

3.5 Wear Analysis

Wear was measured for the substrate and the SAL. Wear rate for the substrate was 14.78 x 10^{-4} mm^3/m and 1.84 x 10^{-4} mm^3/m for the SAL. Figure8 shows the wear graph for the substrate. The wear graph for the SAL is shown in Figure9. The reduction in the wear rate is credited to the presence of intermetallic phase and grain refinement in the SAL. Coefficient of Friction increases marginally from the substrate to the SAL.

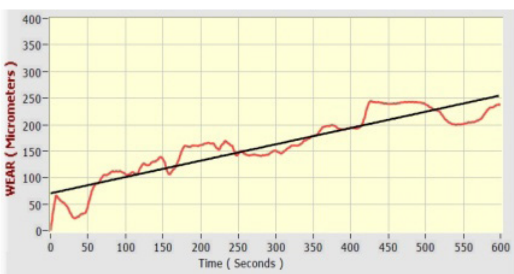

Figure 8. Wear graph for the substrate.

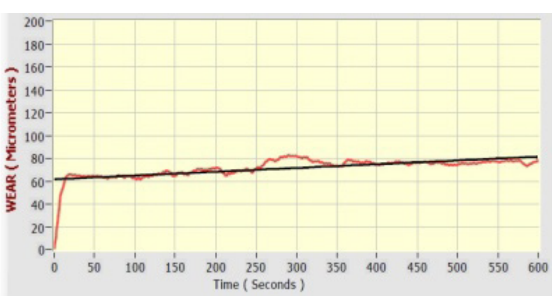

Figure 9. Wear graph for the Surface alloyed layer.

4. Conclusions

The following conclusions are inferred from the investigation conducted.

(1) Surface alloying of AISI304 stainless steel with Ti can be achieved using GTA as heat source. (2)Due to rapid cooling achieved in SAP, an extremely refined grain structure is formed. (3) Hardness increased from 267.5 HV for the substrate to 2098 HV for the SAL because of the formation of an intermetallic phase due to the Ti addition and the grain refinement in the SAL. (4) Reduction in the wear rate is credited to the increase in hardness due to the presence of intermetallic phase and grain refinement.

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