Analysis of Borided and Inducted Hardness Tested AISI 304 Steel Rods

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Abstract- **The structures and characteristics of different materials are profoundly altered when the temperature is changed. In this study, rod samples made of AISI 304 medium carbon steel were bored and then hardened and tempered by induction. The goal was to increase the surface layer's hardness. Induction coils are utilised in the process of applying boron paste components to the surfaces of the steel rods. The treated steel rods are put through a series of tests that are designed to analyse both their hardness and their microstructure. In order to evaluate the effectiveness of the treatment on the hardness of the specimens, a total of thirty samples are evaluated using a range of temperatures, dwell times, and feed rates. During the process of tempering, Taguchi optimization is performed in a furnace to optimize the better parameter results for removing internal stresses. This is done so that the stress can be eliminated. The scanning electron microscope (SEM) and the optical microscope are the two types of instruments that are used in the process of analysing materials for both their chemical composition and their microstructure. The formation of martensitic structures has contributed to an increase in the material's hardness values. At temperatures between 800 and 850 degrees Celsius, the values of the material's hardness are lower, while at a temperature of 1208 degrees Celsius, the maximum value of the hardness is 690 HV. According to the results of laboratory tests, an increase in temperature results in an increase in the surface hardness of AISI 304 steel. The results of the comparison show that AISI 304 steel that has been subjected to both boron and induction treatments has a greater hardness value than AISI 304 steel that has only been subjected to induction treatment.**

Keywords: **Hardening, Microstructure, Dwell Time, Boriding, Tempering.**

I.INTRODUCTION

Induction hardening of metals is more practical than the more laborious and time-consuming process of hardening the metals themselves, which is the traditional method. In materials engineering, the goal is to produce materials in quantities small enough to be useful while simultaneously converting fundamental elements into finished products [1]. Geometrical precision and other quality tolerances are absolutely necessary for the finished product to function as intended after it has been manufactured. Those who are interested in manufacturing should pay careful attention to the selection of materials as a result [2]. Because there is such a vast selection of materials available today, manufacturers are able to create a diverse range of products. When it comes to products that must be resistant to corrosion [3–4], steel is the material of choice. Carbon steels, which are iron alloys with variable amounts of carbon atoms, can contain a wide variety of impurities. Carbon steels are defined as "iron alloys with carbon atoms." There is a one-to-one relationship between the amount of carbon in carbon steel and the material's ductility and strength. The quality of the steel improves as the carbon content rises, but this comes at the expense of its ductility [5–7]. If the user so chooses, the carbon steel AISI 304 can be hardened and then tempered. Because of how the material is made, its surface is meant to be scratch-resistant in a number of high-tech settings.

Surfaces that have been engineered may be able to withstand more wear. Surface hardness, scratch resistance, and wear resistance may all be improved through the use of methods that have been approved for use in industry [8]. Metals and other conductive materials are frequently subjected to induction heating in order to bind, harden, or otherwise modify their properties in some other way. The efficiency, swiftness, and lack of touch exhibited by this approach to heating conductive materials have earned it high praise. An alternating current source is used to provide power to a heating coil that uses induction [9–11]. Eddy currents and magnetic hysteresis are responsible for its heating. In the current method of manufacturing, induction heating [12] provides all three of the following benefits: speed, control, and uniformity. [13]. The metal workpiece is then placed inside the coil, which has a high-frequency voltage applied to it, and the coil is then set up with an alternating flux. It is possible to generate heat by reducing the flux and generating a voltage within it, which then travels through the workpiece [14, 15].

Boriding is a thermo-synthetic surface hardening method that is used to extend the life of metal components and make them more useful [16]. By utilising this technique, friction can be reduced, surface hardness can be increased, and resistance to corrosion can be improved. Heating very specific materials at high temperatures in order to produce boron requires extremely high temperatures. [17, 18]. Borides are produced on the surfaces of materials as a result of the penetration of boron particles into the substance. Borides can be made from low- and medium-carbon alloys [19]. Both simulation and experiment were used to determine the temperatures of equilibrium for critical phase transitions. In order to effectively develop and optimise induction hardening procedures, the initial modelling methodology effectively predicted the hardness of the material as well as its microstructure [20]. The effect of magnetic treatment on mechanical characteristics was investigated by contrasting the microhardness and microstructures of steel samples that had been treated with magnets with those that had not been subjected to the treatment. Even though wet hard machining was used in an effort to cut down on stress levels, there was still evidence of residual stress [21–25]. For accurate control of the parameters of the gear wheel induction surface hardening process, you need high-tech measuring tools.
Induction and conventional heat treatment result in different microstructures for 42CrMO4 steel. The process of induction hardening may be advantageous for materials that are subjected to heavy loads, particularly those that are subjected to torsional stresses and surfaces that are subjected to high impact loads. When it comes to martensite tempering, the carbon concentration, temperature, and amount of time spent in the quench are all critically important parameters [26–28]. All of these factors have an influence on the maximum hardness that the steel can achieve. The ability of induction to be machined
This research project is focusing its attention on borided steels. When working with AISI 304 medium carbon steel, a number of different processes, such as boring, hardening, and tempering, are utilised. [Citation needed]

II.EXPERIMENTAL WORK

2.1 Materials Selection

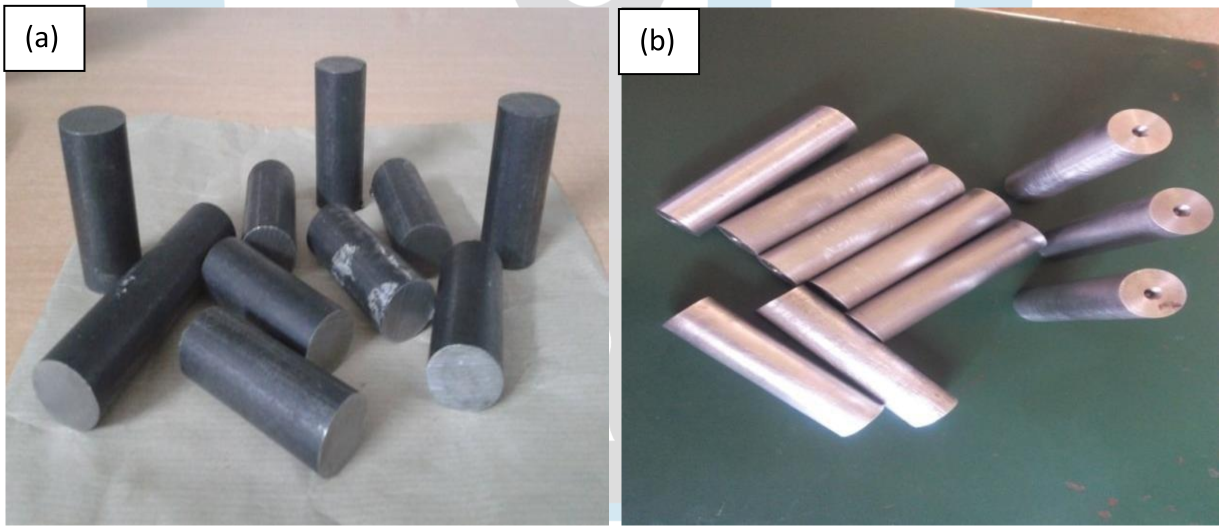


Figure 1: Materials for Experimental (a) AISI 304 Steel (b) Surface Finishing of AISI 304 Steel

Boride paste and AISI 304 carbon steel were used to coat the carbon steel surfaces that were exposed during the experiment. In accordance with the norms established by the industry, a sample of medium-carbon steel measuring 70mm in length and 20mm in diameter was produced. If you want them black, you have the option of having them hot-rolled or normalised. In general, this steel is held in very high regard due to its ability to be machined and welded, as well as its strength and resistance to impact. It is possible to achieve normalised (or hot-rolled) hardness through the process of induction hardening [29].

Table 1: AISI 304 Steel Chemical Compositions

Elements (%)							
Iron (Fe)	**Chromium (Cr)**	**Nickel (Ni)**	**Manganese (Mn)**	**Silicon (Si)**	**Carbon (C)**	**Phosphorus (P)**	**Sulphur (S)**
Bal	18	9.5	2	1	0.08	0.04	0.03

When it comes to surface hardening, medium-carbon steel is widely considered to be one of the most effective materials. Figure 1 (a) demonstrates the surface treatment that was applied to AISI 304 steel, as does Figure 1 (b). The removal of unwanted chemicals as well as metal components is a part of the surface polishing process. In order to make it easier for carbon atoms to travel through the boride paste while it is being heated [30], the specimen is given a glass-polished surface after being machined on a lathe. Induction hardening has the potential to improve both the ferrite and pearlite structures of the SAE-AISI 304 steel material that is shaped like rods.

Table 2: Boriding Paste various composition

Elements	Weight (%)
Silicon Carbide (SiC)	50
Boron Carbide (B_4C)	30
Potassium Tetra Fluro Borate (KbF_4)	10
Sodium Carbonate (Na_2Co_3)	5
Titanium Dioxide (TiO_2)	5

The chemical components of the bonding paste are broken down and presented in Table 2, along with the relative weight percentages of each component. The primary component of bore paste is silicon carbide, and it also contains a trace amount of sodium carbonate and titanium dioxide. Boron can be deposited onto metal surfaces through the application of heat and certain chemicals. Boride pastes are frequently used as a coating [31, 32] because they are able to increase both the surface area and the hardness of a material.

2.2 Induction Boriding Process

One of the most promising industrial technologies is creating a steel surface that is exceptionally hard to the touch. Wear resistance is provided by the presence of borate layers on steels in the same way that sintered carbides are. When compared to other methods of surface hardening, boring has the ability to produce a level of surface hardness that ranges from 1,400 to 2,100 HV. There is no difference in wear resistance between boride-coated steels and sintered carbides. Boronizing AISI 304 medium carbon steel requires taking into consideration the relevant dimensions [33, 34]. There is sufficient space in the example for you to store everything that you require. On each of the material samples, an equal amount of borate paste was carefully applied. Figures 2a and 2b depict AISI 304 carbon steel that has been modified by the addition of boron compounds. When applying the boride paste, it was essential to make use of materials that were wet. Before beginning the process of the surface becoming harder, it is necessary to let it dry in the sun for a period of thirty minutes. Using boride paste makes it possible to improve the surface's qualities, such as making it harder.

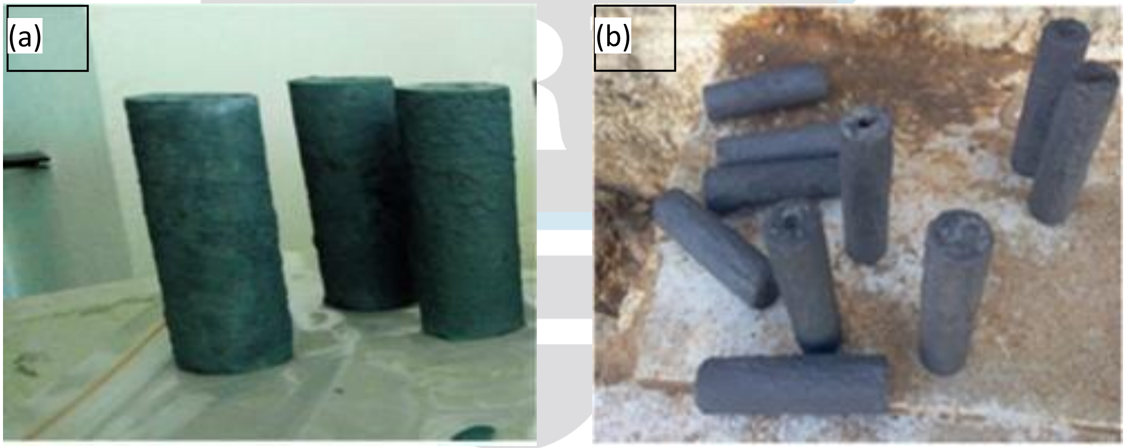


Figure 2: AISI 304 Carbon Steel Experimental
(a) AISI 304 Induction Borided Steel (b) after Boride applied of AISI 304 steel.

2.3 Induction Surface Hardening

When it comes to heating metal components, induction hardening is superior to more conventional heating methods. Carbon content is the primary factor in determining the surface hardness of steel, which in turn increases the material's resistance to wear [35, 36]. The best heating services in Coimbatore, operating in the 21st century, performed induction hardening on carbon steel. During the process of hardening, temperatures can range anywhere from 780 to 1200 degrees Celsius. Steel must have a diameter of 25mm and a length of 75mm in order to be inducted-hardened. An induction coil is used to heat the steel rods, which have a specification of AISI 304. The coil is warmed by the transformer in this arrangement. The induction coil receives its power from the transformer, which is supplied by the source of alternating current. Steel with an AISI 304 designation can be hardened using this method.

2.4 Surface Tempering Process

When tempering at temperatures lower than the critical range, normalised steel is the type of steel that is used. In order to produce the desired results with the material's mechanical properties, it must first be heated and then allowed to cool slowly for a set amount of time. Because tempering occurs at a particular temperature, the hardness and strength of the finished product are both determined by that temperature. The brittleness of quenched steel can sometimes be reduced through the use of surface tempering procedures. The increase in ductility that comes from higher temperatures comes at the expense of the material's strength and hardness [37,38].In these experiments, hardening and tempering processes are used to modify the material.

III. Results and Discussions

The experimental investigation of this study focuses on induction-borided AISI 304 medium carbon steel as its primary material of interest. Boring and hardening rods made of AISI 304 medium-carbon steel required a number of different types of testing, including microstructure, hardness, and scanning electron microscopy (SEM). The outcomes of an experiment are validated when they are compared to the outcomes of existing systems. This ensures that the outcomes of the experiment are accurate.

3.1 Hardness of Boride Induction Treated 304 Steel

Boride and induction hardening were used on a rod made of AISI 304 medium steel in order to determine the rod's hardness. Because each of these parameters was tested in at least thirty distinct ways, the findings are representative of the whole. The results are presented in the following table:

Table 4: The hardness factors and level of response in AISI 304 carbon steel

Sl.No.	Gap (mm)	Current (Amp)	Dwell Time (sec)	Feed Rate (mm/s)	Attained Temp. (^{0}C)	Borided Hardness of AISI 304 steel (100gm) (Hv)
1	5	125	5	2	1000	611
2	5	140	5	4	1170	629
3	5	125	7	2	1100	614
4	5	125	7	4	900	609
5	5	140	5	2	989	669
6	5	135	5	4	900	612
7	5	140	7	2	1200	682
8	7	135	7	4	1100	589
9	7	125	5	2	1150	611
10	7	120	5	4	810	562
11	7	120	7	2	812	576
12	6	125	7	4	850	585
13	5	120	7	2	800	597
14	5	140	6	4	1167	609
15	7	140	7	2	1190	674
16	6	135	7	4	910	613
17	6	130	5	3	979	622
18	6	130	6	5	965	619
19	4	130	4	3	964	614
20	6	140	8	5	1208	689
21	6	120	6	3	800	549
22	4	140	6	3	1180	670
23	8	130	6	3	976	619
24	6	130	6	3	980	597
25	6	130	6	3	976	616
26	6	130	6	3	980	627

27	6	130	6	3	981	629
28	6	125	6	3	780	592
29	6	125	6	3	784	593
30	6	125	6	3	786	592

The results of hardness tests conducted on treated rods made of AISI 304 carbon steel are presented in Figure 3. As can be seen in Table 4, the thirty tests cover a wide range of variables, including gap, current flow, feed rate, temperature, and dwell duration. When heated to 1208 degrees Fahrenheit, the material reaches its maximum hardness of 690 HV. The most difficult material to work with was steel rod, which required a maximum spacing of 6 mm, a maximum current of 140 amps, a dwell time of 8 seconds, and a feed rate of 5 mm per second. A test of the material's hardness is employed in order to tensile strength of materials for steel [39, 40].

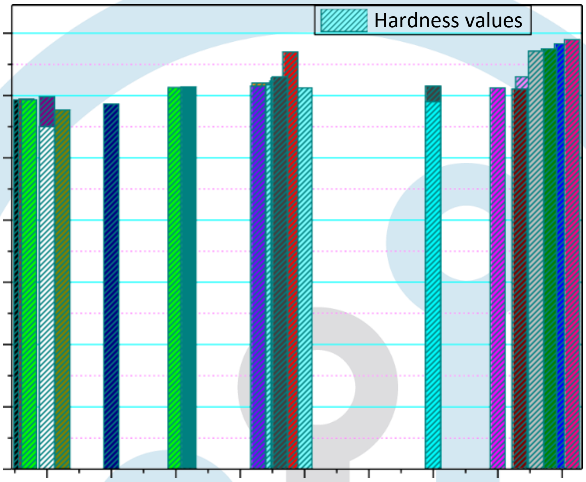
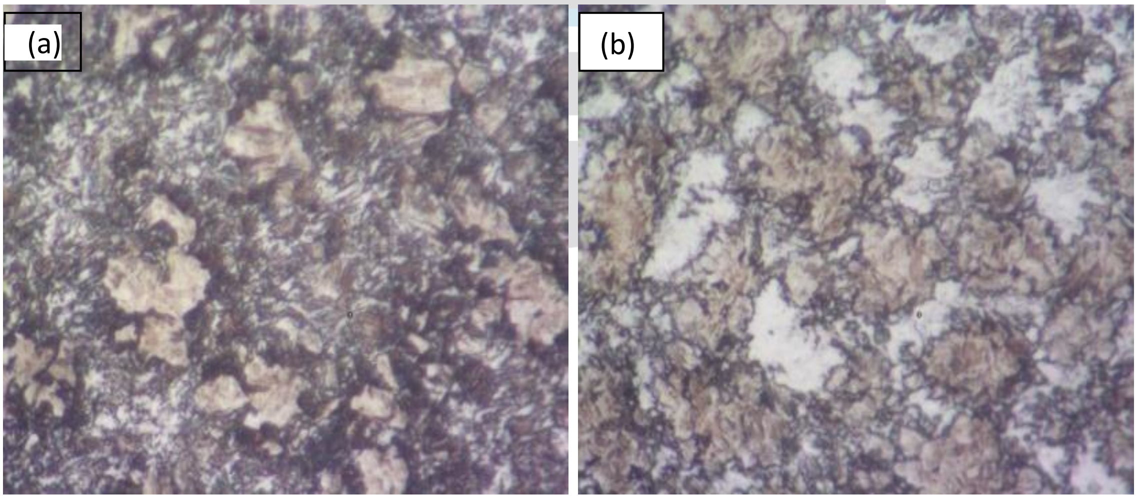


Figure 3: AISI 304 carbon steel hardness and temperature

3.2 Microstructure Analysis

The microstructure of the steel rods shown in Figure 4 has been altered as a result of being treated with AISI 304, as shown by the images taken with a scanning electron microscope. A picture of the material's microstructure is shown for a range of hardness that goes from 690 to 550. The formation of partial martensite and a subsequent decrease in surface hardness were both caused by the lower temperatures at which the material was hardened. Between a temperature range of 780 and 1200 degrees Celsius, the hardness of the material steadily increased from 550 HV to 690 HV as it went through the process of hardening. When the temperature exceeds 1200 degrees Celsius, an exponential increase in the number of martensitic structures occurs, which reaches its peak at that point. At a temperature of 1100 degrees Celsius, the test produced a martensitic structure. The structure of the substrate is ferrite-pearlite, while the structure of the surface layer is martensitic [42].



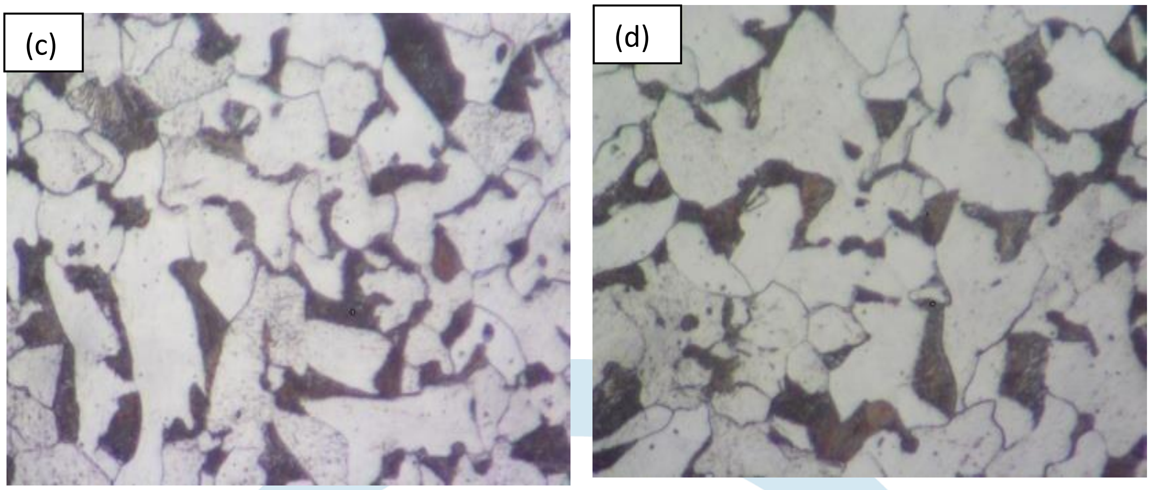
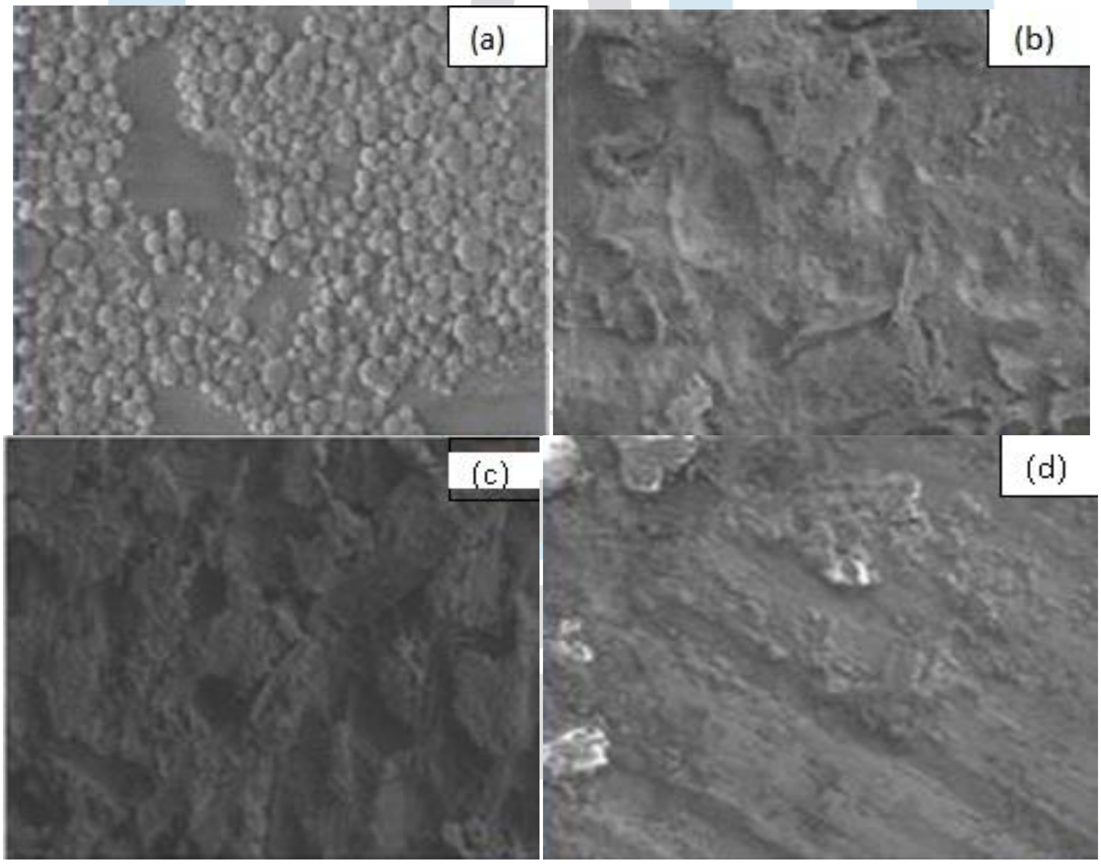


Figure 4: Treated AISI 304 carbon steel microstructure (a) 690 HV
(b) 683 HV (c) 563 HV and (d) 550 HV

3.3 Scanning Electron Microscopy

Figure 5 demonstrates that SEM pictures of AISI 304 steel materials contain images with a range of nm sizes that includes 1, 2, 10, 20, 100, and 200. During the SEM examination, an electron beam is used rather than a light source as the primary light source. Microstructural images of treated components made of AISI 304 steel can be seen in these images.



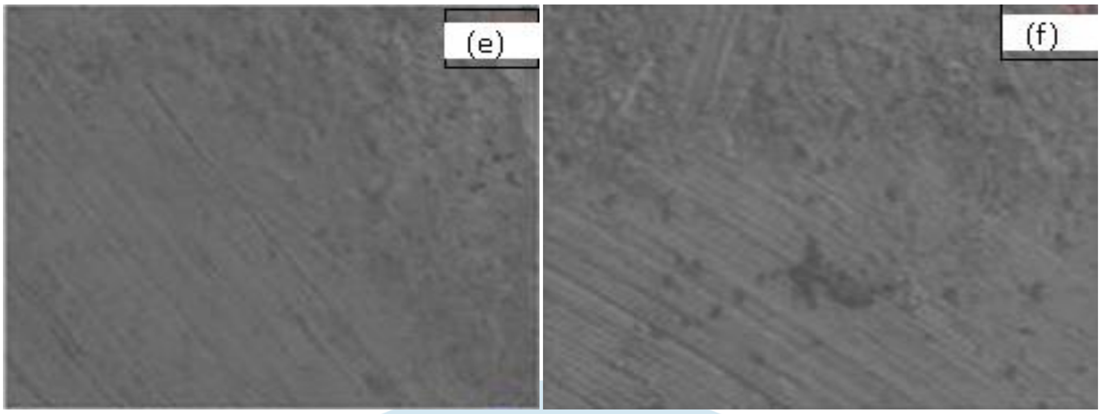


Figure 5: AISI 304 steel scanning electron microscopy analysis

3.4 Taguchi Optimization

This research makes use of Taguchi optimization to identify the factors that have the greatest impact on the outcome. Influence on the level of hardness exhibited by AISI 304 steel rods. As a direct result of this, Taguchi Optimization favours an increased signal-to-noise ratio of the data The fundamental mathematical concepts for the necessary circumstances are as follows:

$$\frac{S}{N} = -10\log((\sum_0^n(\frac{1}{y2})/n) \quad (1)$$

In order to calculate the S/N ratios, the hardness of the boron induction-treated 304 steel rods has been plugged into the equation that was presented earlier. Table 5 presents the S/N ratios for various hardness values for your perusal.

Table 5: Process parameters of the S/N ratio

Sl.No	Gap (mm)	Current (Amp)	Dwell time (sec)	Feed rate (mm/s)	Attained temp. (^{0}C)	Hardness By Induction Borided Process 100 gm (Hv)	S/N Ratio (dB)
1	5	125	5	2	1000	611	55.73
2	5	140	5	4	1170	629	55.98
3	5	125	7	2	1100	614	55.84
4	5	125	7	4	900	609	55.70
5	5	140	5	2	989	669	56.52
6	5	135	5	4	900	612	55.74
7	5	140	7	2	1200	682	56.68
8	7	135	7	4	1100	589	55.41
9	7	125	5	2	1150	611	55.73
10	7	120	5	4	810	562	55.01
11	7	120	7	2	812	576	55.22
12	6	125	7	4	850	585	55.33
13	5	120	7	2	800	597	55.53
14	5	140	6	4	1167	609	55.70
15	7	140	7	2	1190	674	56.58
16	6	135	7	4	910	613	55.76
17	6	130	5	3	979	622	55.88
18	6	130	6	5	965	619	55.84
19	4	130	4	3	964	614	55.77
20	6	140	8	5	1208	689	56.77
21	6	120	6	3	800	549	54.80
22	4	140	6	3	1180	670	56.53
23	8	130	6	3	976	619	55.84
24	6	130	6	3	980	597	55.53
25	6	130	6	3	976	616	55.80

26	6	130	6	3	980	627	55.95
27	6	130	6	3	981	629	55.98
28	6	125	6	3	780	592	55.46
29	6	125	6	3	784	593	55.47
30	6	125	6	3	786	592	55.46

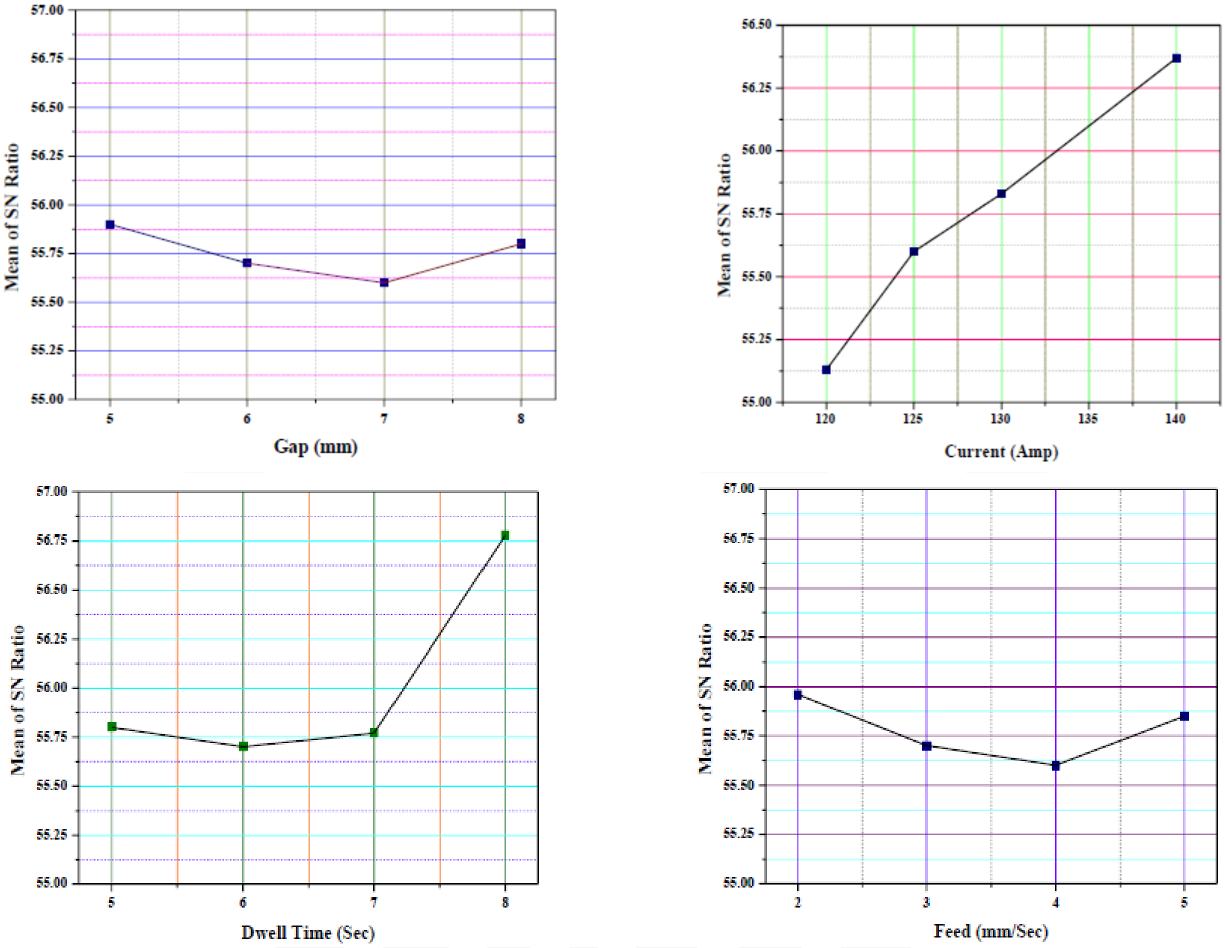


Figure 6: S/N Ratio Parameters in a Main Effect Plot (a) Gap (b) Current

(c) Dwell Time (d) Feed Rate in mm/Sec

Charts depicting each sample's S/N ratio can be found in Figure 6, which can be found here. In the graph that is located above, each of these variables has been displayed as a S/N ratio. Dwell time has been shown to be the most important factor in the hardness improvement of AISI 304 steel rods [43], despite the fact that current rates have had a significant influence on both the decline and improvement of hardness. When applied to rods made of AISI 304 steel, the induction-boring process can produce a high level of hardness by decreasing the spacing, feed rate, dwell time, and current. The ideal parameters for the Taguchi process are five mm of spacing, 140 amps, a feed rate of two mm per second, and an eight-second dwell time.

3.5 Validation of the Results of the Investigation

This section examines the similarities and differences between the boride and induction processes and the induction process. (You can find both of them in Table 6. Borided and induction-hardened medium-carbon AISI 304 steel was the material of choice for this project. Experiments are performed in order to determine the varying degrees of hardness. According to the findings of previous studies, it is common knowledge that AISI 1040 medium steel [44] can be induction hardened. A comparison of the proposed boriding and hardening processes with the actual hardness values provides support for the study's conclusions. When using an induction process to harden AISI 304 steel components, it is necessary to collect data on the hardness of the steel in terms of current, feed rate, dwell duration, and other parameters in order to validate the results indicated. After that, we will evaluate the new findings in light of the traditional approach, which will continue to be utilised.

Table 6: The borided with induction process and induction process experiment results

Sl. No	**Gap (mm)**	**Current (Amp)**	**Dwell time (sec)**	**Feed rate (mm/s)**	**Attained temp. (^{0}C)**	**Hardness of Induction Borided Treated AISI 304 steel rods 100gm (Hv)**	**Hardness of Induction Heat Treated AISI 304 steel rods 100gm (Hv)**
1	5	125	5	2	1000	611	600
2	5	140	5	4	1170	629	620
3	5	125	7	2	1100	614	603
4	5	125	7	4	900	609	599
5	5	140	5	2	989	669	652
6	5	135	5	4	900	612	600
7	5	140	7	2	1200	682	660
8	7	135	7	4	1100	589	587
9	7	125	5	2	1150	611	603
10	7	120	5	4	810	562	547
11	7	120	7	2	812	576	549
12	6	125	7	4	850	585	557
13	5	120	7	2	800	597	578
14	5	140	6	4	1167	609	596
15	7	140	7	2	1190	674	657
16	6	135	7	4	910	613	603
17	6	130	5	3	979	622	609
18	6	130	6	5	965	619	607
19	4	130	4	3	964	614	609
20	6	140	8	5	1208	689	671
21	6	120	6	3	800	549	531
22	4	140	6	3	1180	670	654
23	8	130	6	3	976	619	610
24	6	130	6	3	980	597	578
25	6	130	6	3	976	616	605
26	6	130	6	3	980	627	612
27	6	130	6	3	981	629	613
28	6	125	6	3	780	592	574
29	6	125	6	3	784	593	574
30	6	125	6	3	786	592	573

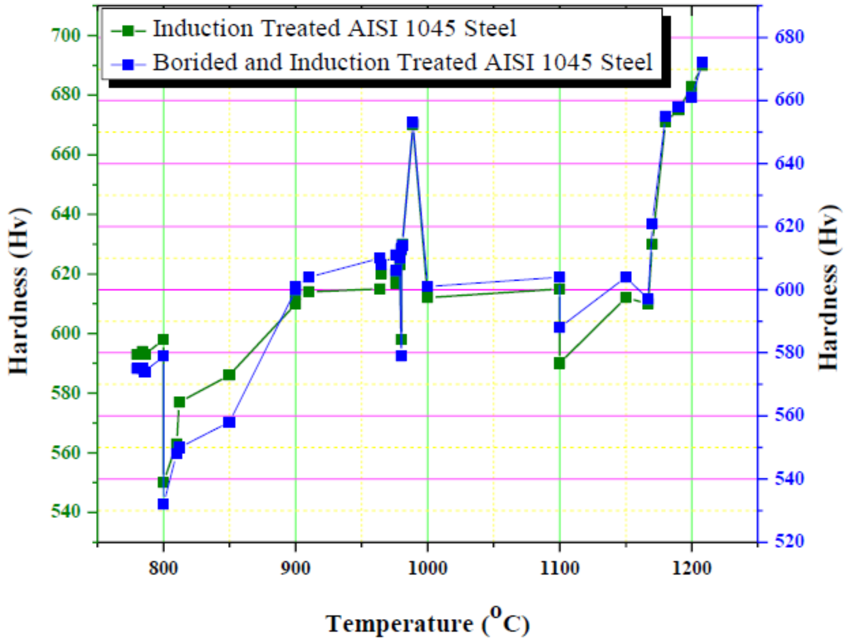


Figure 7: The method for verifying experimental results

As can be seen in Figure 7, our findings are supported by the results of an experiment. There is a visual representation of AISI 304 steel samples that have been subjected to boriding and hardening. As can be seen in the graph located above, the proposed boring and hardening methods worked better and produced better results when applied to medium carbon steel. The method that is described results in an increase in the hardness and strength of the specimens. If you bore the material instead of just hardening it, you can make a stronger material.

V.CONCLUSION

According to the findings of this study, which investigated the surface hardness of AISI 304 carbon steel, fluctuations in temperature have a significant impact on the structure as well as the chemical properties of materials. These processes are used to harden and temper AISI 304 steel in order to improve both the structure and toughness of the material. The Taguchi optimization method can be utilised to enhance the process parameters of AISI 304 carbon steel, fluctuations in temperature have a significant impact on the structure as well as the chemical properties of materials. These processes are used to harden and temper AISI 304 steel in order to improve both the structure and toughness of the material. The Taguchi optimization method can be utilised to enhance the process parameters. Between 800 and 810 ºC is where you will find the softest values of hardness, while 1208ºC will produce the hardest values of 689 HV. After being cooled and tempered, martensite transforms into a ferrite-carbide combination. This transformation takes place chemically. The temperature of 430ºC is the point at which the surface hardness and corrosion resistance of materials made from AISI 304 steel reach their maximum levels. According to the findings, a higher temperature during the tempering and hardening processes of AISI 304 steel results in a greater increase in surface hardness. Hardness is measured on Rockwell, bored and hardened AISI 304 steel has a higher level of hardness than unhardened AISI 304 steel. Hardening the metal can be accomplished through a process known as boring and induction hardening of AISI 304 steel rods. After some time has passed, scientists may decide to investigate the factors that lead to a reduction in the tensile strength of materials after they have been treated. It is possible, through the application of processes such as annealing, to increase both the ductility and the tensile strength of AISI 304 steel. Several methods, such as hardening, tempering, and quenching, can be used to improve the quality of materials.

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