Evaluation of Hardness of AISI 1045 Steel Rods Tested by Borided and Inducted

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Abstract

Temperature has a significant impact on the properties and structures of materials. This research used boriding and subsequent induction hardening and tempering of AISI 1045 medium carbon steel rod samples in order to improve the hardness of the surface layer. Induction coils are used to add boron paste components to the steel rods' surfaces. Testing is used to assess the hardness and microstructure of the treated steel rods. A total of 30 samples are tested at different temperatures, dwell durations, and feed rates to determine the hardness of the treated specimens. As part of the tempering process, Taguchi Optimization is carried out in a furnace to determine the best parameter values for eliminating internal stresses. Two types of instruments are utilised to examine materials for their chemical composition as well as their microstructure: the Scanning Electron Microscope (SEM) and the Optical Microscope. As a result of the emergence of martensitic structures, hardness values have risen. Lower hardness values are obtained at temperatures between 800 °C and 850 °C, whereas 690 HV is the maximum hardness measured at 1208 °C. Increased temperature increases AISI 1045 steel's surface hardness, according to

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lab testing. According to the compared results, AISI 1045 steel that has been boron and induction treated has a higher hardness value than AISI 1045 steel that has been induction treated.

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

Introduction

It is more practical to harden metals through induction than by hardening, which is more difficult and time-consuming. In materials engineering, the objective is to produce materials in small enough quantities to be useful while also converting basic elements into completed commodities [1]. For a completed product to function properly, geometrical precision and other quality tolerances are crucial. Those with an interest in manufacturing should thus pay close attention to the selection of materials [2]. With today's huge array of materials, manufacturers may now develop a wide range of items. Steel is the material of choice for corrosion-resistant applications [3–4]. There are a variety of impurities in carbon steels, which are iron alloys with carbon atoms that are present in varying amounts. In terms of ductility and strength, carbon steel has a direct correlation to its carbon content. Due to an increase in carbon content, steel quality improves, but ductility decreases [5-7]. The carbon steel AISI 1045 may be hardened and tempered if desired. The material is designed to provide a scratch-resistant surface in numerous high-tech applications.

Engineered surfaces may be able to withstand more wear. The adoption of industrially authorised methods may improve surface hardness, scratch resistance, and wear resistance [8]. Induction heating is often used to bind, harden, or otherwise modify the characteristics of metals and other conductive materials. This method of heating conductive materials is praised for its effectiveness, speed, and lack of touch. An induction heating coil is powered by an alternating current source [9–11]. It is heated by eddy currents and magnetic hysteresis. Speed, control, and uniformity are all provided by induction heating [12] in the current manufacturing method. [13]. Coils with an alternating flux are set up with a high-frequency voltage, and the metal workpiece is put inside of the coil. Heat can be made by lowering the flux and creating a voltage in it, which moves through the workpiece [14, 15].

A thermo-synthetic surface hardening method called boriding is used to increase the life and usefulness of metal components [16]. This technique reduces friction, increases surface hardness, and enhances corrosion resistance. In order to create boron, high temperatures are needed to heat very precise materials. [17, 18]. Borides form on the surfaces of materials as boron particles penetrate the substance. Alloys with low and medium carbon may be borided [19]. simulation and experimentally determined equilibrium temperatures for critical phase changes. The initial modelling methodology effectively predicted hardness and microstructure in order to develop and optimise induction hardening procedures [20]. The effect of magnetic treatment on mechanical characteristics was studied by comparing the micro-hardness and microstructures of treated and untreated steel samples. To reduce stress levels, wet hard machining was used; nonetheless, residual stresses were still present [21–25]. Sophisticated measurement equipment is required for accurate control of the gear wheel induction surface hardening process parameters.

Microstructure of $42CrMO_4$ steel after induction and conventional heat treatment Induction hardening may be beneficial to heavy-loading materials, particularly those subjected to torsional stresses and surfaces subjected to high impact loads. During martensite tempering, carbon concentration, temperature, and time of quenching are all crucial parameters [26-28]. The ultimate hardness of the steel is affected by all of these factors. The machinability of induction-borided steels is the focus of this research project. Boring, hardening, and tempering are just a few of the processes that are used while dealing with AISI 1045 medium carbon steel.

Experimental Work

Selection of Materials

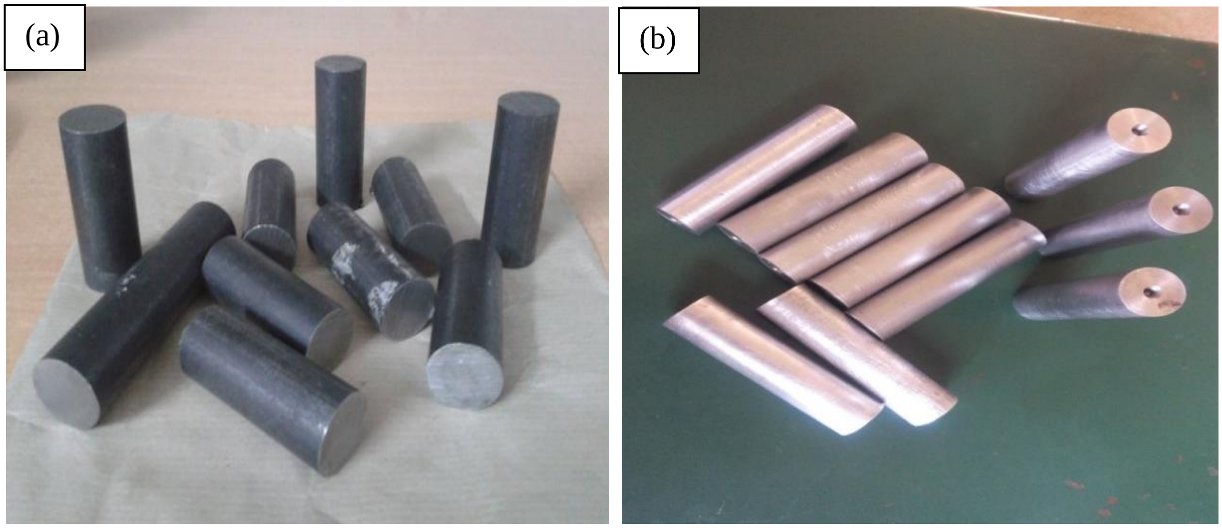

Figure 1: Experimental Materials (a) AISI 4015 Steel (b) AISI 1045 Steel after Surface Finishing

In the experiment, the carbon steel surfaces were coated with boride paste and AISI 1045 carbon steel. A medium carbon steel sample of 70 mm in length and 20 mm in diameter was manufactured in accordance with industry standards. Hot rolled or normalised are two options if you want them black. Overall, this steel is highly respected for its capacity to be machined, welded, be strong, and impact resistant. Normalized (or hot rolled) hardness may be achieved through induction hardening [29].

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Table 1: The Chemical Composition of AISI 1045 Steel

Grade	Elements (%)				
	Carbon (C)	Chromium (Cr)	Molybdenum (Mo)	Tungsten (W)	Vanadium (V)
M2	0.95	0.004	5	6.0	2.0

Medium carbon steel is often regarded as one of the best solutions for surface hardening. The surface treatment of AISI 1045 steel is shown in Figure 1 (a) and (b). Surface polishing includes the removal of unwanted chemicals and metal components. The specimen is machined in a lathe with a glass polished surface in order to facilitate the passage of carbon atoms during boride paste heating [30]. The SAE-AISI 1045 rod-shaped steel material's ferrite and pearlite structure may be improved by induction hardening.

Table 2: The Various Composition of Boriding Paste

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

Table 2 shows the chemical composition of the boriding paste, as well as the weight percentages of each element. Bore paste is mostly made of silicon carbide with a little quantity of sodium carbonate and titanium dioxide. Boron may be applied to metal surfaces using heat and chemicals. In [31, 32], when increasing a material's surface area and hardness, boride pastes are often employed as a coating.

Induction Boriding Process

One of the most promising industrial technologies for producing a steel surface with an extraordinarily hard surface. Boride layers on steels provide wear resistance in the same manner as sintered carbides do. Boriding is capable of creating a surface hardness of between 1400 and 2100HV when compared to other techniques of hardening. Sintered carbides and boride-coated steels have the same wear resistance. Boronizing AISI 1045 medium carbon steel necessitates that the relevant dimensions be considered [33, 34]. There's enough room in the sample to fit everything you need. Boride paste was applied equally and gently to the material samples. Figure 2(a) and (b) show the AISI 1045 carbon steel with boron compounds added to it. It was necessary to use wet materials for applying the boride paste. It is necessary to let the surface dry for 30 minutes in the sun before starting the hardening process. Improved hardness and other surface qualities may be achieved by using boride paste.

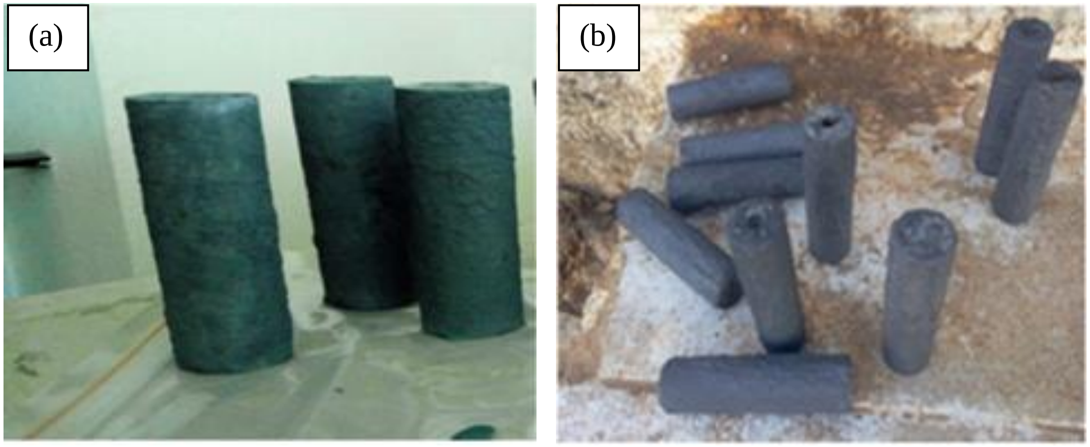

Figure 2: Experimental Material of AISI 1045 Carbon Steel (a) Induction Borided AISI 1045 Steel (b) AISI 1045 Steel after Applied Boride.

Induction Surface Hardening

Induction hardening is better than traditional methods of heating metal components. The steel's surface hardness, which increases its resistance to wear, is determined by the carbon content [35, 36]. Best Heating Services in Coimbatore, 21st Century, conducted carbon steel induction hardening. Temperatures in the hardening process range from 780 to 1200 ^{o}C. Induction hardening requires steel with a diameter of 25 mm and a length of 75 mm. The AISI 1045 steel rods are heated using an induction coil. The transformer serves to warm the coil. The alternating current source provides power to the induction coil from the transformer. This technique is used to harden AISI 1045 steel.

Surface Tempering Process

Table 3. The Chemical Composition of AISI 1045 Steel After Treatment.

Elements	Treated Steel (%)
Carbon (C)	0.43
Iron (Fe)	98.41
Silicon (Si)	0.18
Manganese (Mn)	0.76
Phosphorous (P)	0.012
Chromium (Cr)	0.004
Tungsten (W)	0.013
Aluminium (Al)	0.04

Normalised steel is utilised for tempering at temperatures lower than the critical range. After being heated, the materials are allowed to cool for a period of time in order to achieve the desired mechanical properties. Because tempering takes place at a certain temperature, the final product's hardness and strength are determined by that temperature. Surface tempering procedures may minimise the brittleness of quenched steel. Higher temperatures increase ductility, but at the expense of strength and hardness [37, 38]. Hardening and tempering procedures are used in these experiments.

Results and Discussions

This study's experimental investigation focuses on AISI 1045 medium carbon steel, which is induction-borided. Hardness, microstructure, and scanning electron microscopy (SEM) examinations have all been used to bore and harden AISI 1045 medium carbon steel rods. When the results of an experiment are compared to the results of current systems, the results of the experiment are confirmed.

Hardness of Boride Induction Treated 1045 Steel

An AISI 1045 medium steel rod was evaluated for hardness using boride and induction hardening. The findings are representative since each of these parameters is tested in at least 30 different ways and the results are shown below.

Table 4: The Factors and Level of Responses in Hardness of AISI 1045 Carbon Steel

Sl.No.	Gap (mm)	Current (Amp)	Dwell Time (sec)	Feed Rate (mm/s)	Attained Temp. (^{0}C)	Borided Hardness of AISI 1045 steel (100gm) (Hv)
1	5	125	5	2	1000	612
2	5	140	5	4	1170	630
3	5	125	7	2	1100	615
4	5	125	7	4	900	610
5	5	140	5	2	989	670
6	5	135	5	4	900	613

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7	5	140	7	2	1200	683
8	7	135	7	4	1100	590
9	7	125	5	2	1150	612
10	7	120	5	4	810	563
11	7	120	7	2	812	577
12	6	125	7	4	850	586
13	5	120	7	2	800	598
14	5	140	6	4	1167	610
15	7	140	7	2	1190	675
16	6	135	7	4	910	614
17	6	130	5	3	979	623
18	6	130	6	5	965	620
19	4	130	4	3	964	615
20	6	140	8	5	1208	690
21	6	120	6	3	800	550
22	4	140	6	3	1180	671
23	8	130	6	3	976	620
24	6	130	6	3	980	598
25	6	130	6	3	976	617
26	6	130	6	3	980	628
27	6	130	6	3	981	630
28	6	125	6	3	780	593
29	6	125	6	3	784	594
30	6	125	6	3	786	593

Figure 3 shows the results of hardness tests performed on treated AISI 1045 carbon steel rods. The 30 tests include variables such as gap, current flow, feed rate, temperature, and dwell duration as indicated in Table 4. Hardness readings reach a high of 690 HV at 1208 °C. With a maximum spacing of 6 mm, a maximum current of 140 Amps, a dwell time of 8 seconds, and a

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feed rate of 5 mm/sec, steel rod material was the hardest. A hardness test is used to assess the tensile strength of steel rod materials [39–41].

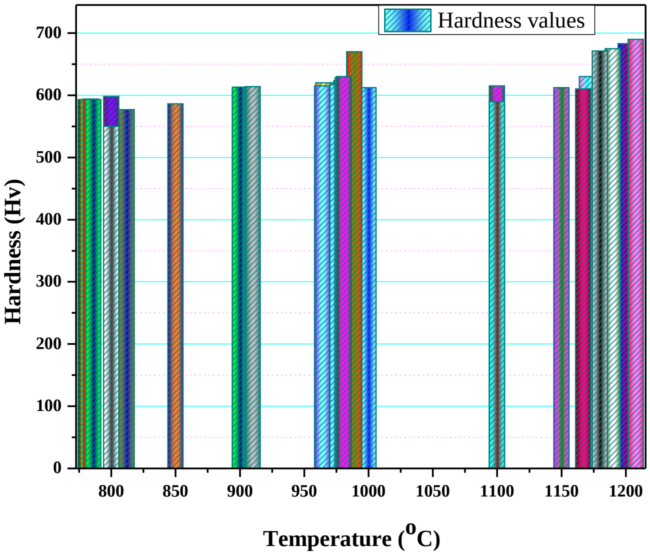

Figure 3: The Hardness and Temperature of the AISI 1045 Carbon Steel

Microstructure Analysis

Images taken with a scanning electron microscope in Figure 4 demonstrate changes in steel rod microstructure after being treated with AISI 1045. An image of the microstructure is displayed for hardness ranging from 690 to 550. Lower hardening temperatures resulted in the formation of partial martensite and a reduction in surface hardness. During the hardening process, the hardness increased steadily from 550 HV to 690 HV between 780 °C and 1200 °C. As the temperature rises over 1200 °C, the number of martensitic structures climbs exponentially, culminating at that point. The test generated a martensitic structure at 1100°C. The structure of the surface layer is martensitic, while the structure of the substrate is ferrite-pearlite [42].

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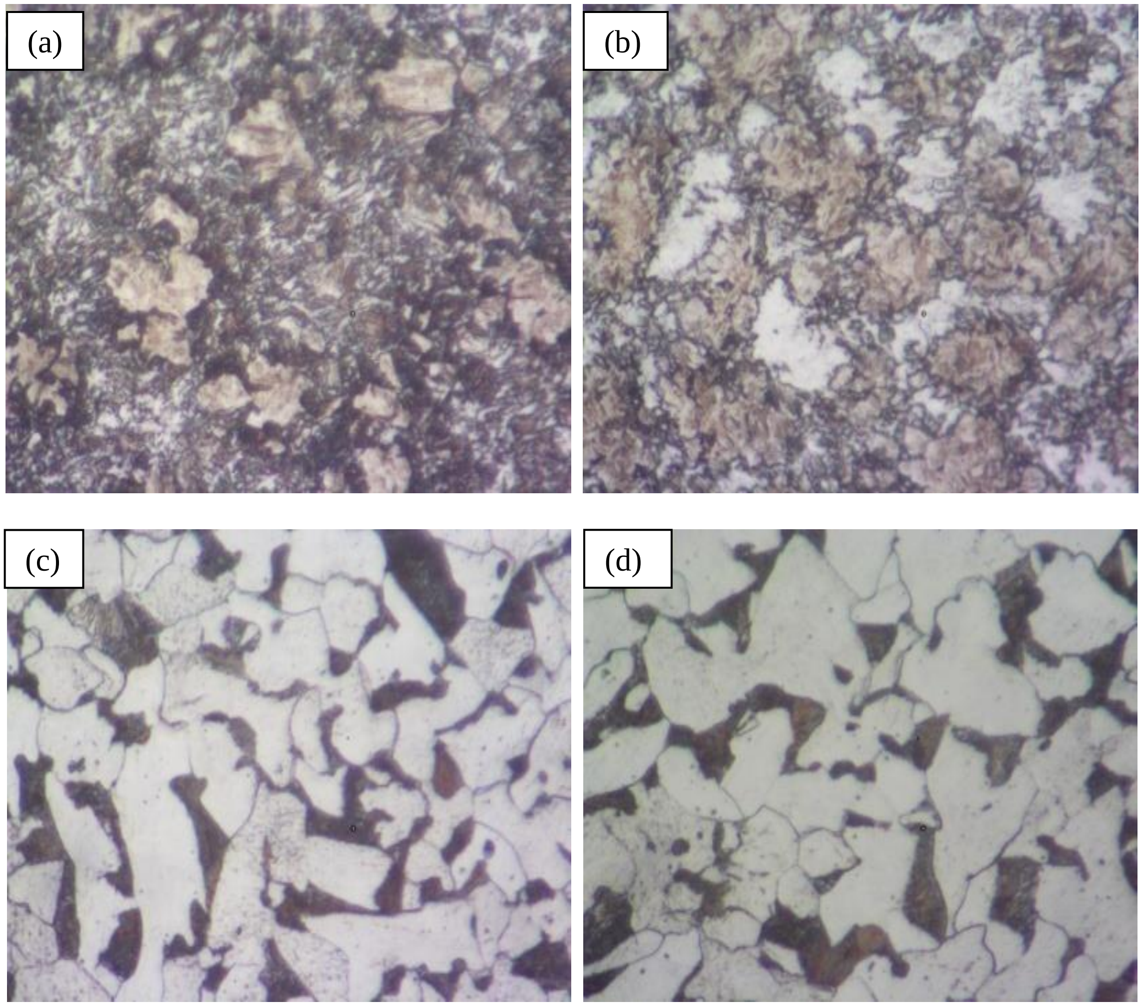


Figure 4: Microstructure of Treated of AISI 1045 Carbon Steel (a) 690 HV (b) 683 HV (c) 563 HV and (d) 550 HV

Scanning Electron Microscopy

As can be seen in Figure 5, SEM pictures of AISI 1045 steel materials include images with a nm size range of 1, 2, 10, 20, 100, and 200. Instead of a light source, an electron beam is employed in the SEM examination. These images show micro structural images of AISI 1045 steel components that have been treated.

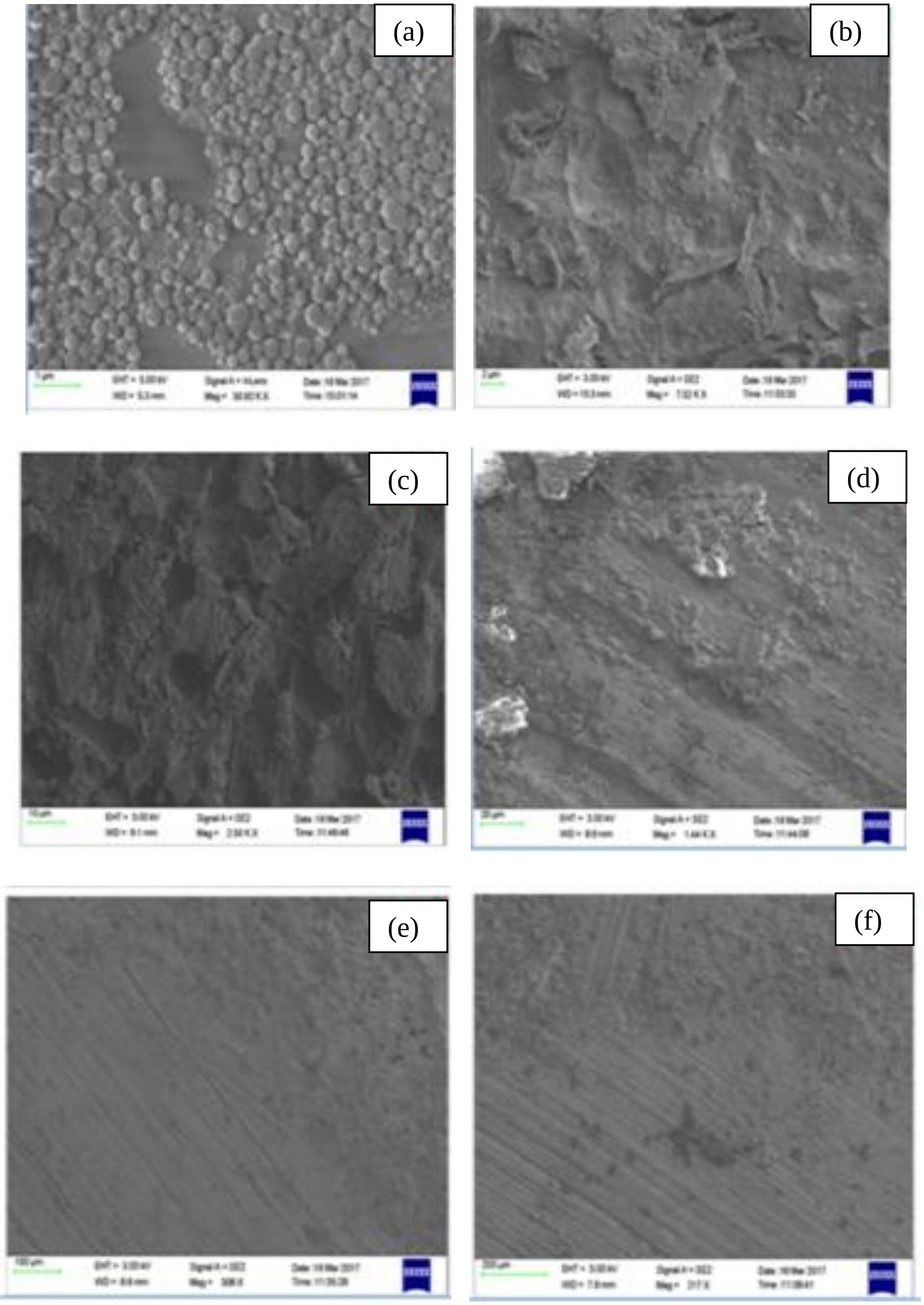


Figure 5: Scanning Electron Microscopy Analysis of AISI 1045 Steel

Taguchi Optimization

Taguchi Optimization is used in this research to find the elements that have the greatest impact on the hardness of AISI 1045 steel rods. Consequently, Taguchi Optimization favours a higher ratio of signals to noise. The underlying mathematics for the required situations (1),

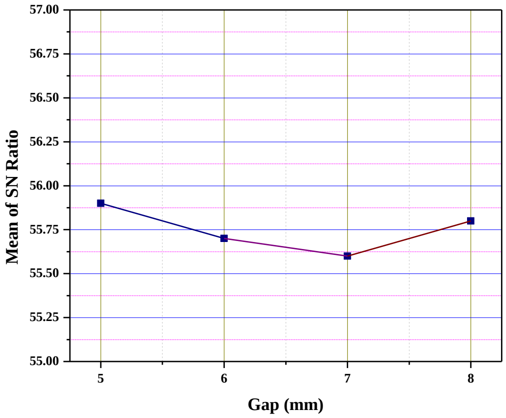
$$S / N = -10 * \log_{10}((\sum \frac{1}{y^2}) / n) \qquad (1)$$

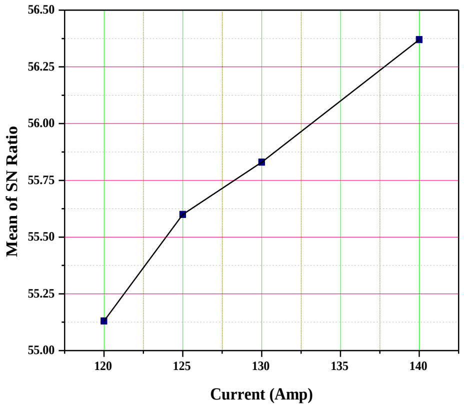
The hardness of Boride Induction Treated 1045 steel rods is inserted into the equation above in order to arrive at the S/N ratios. The S/N ratios for hardness vales are shown in Table 5.

Table 5: SN Ratio for the Process Parameters

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	612	55.73
2	5	140	5	4	1170	630	55.98
3	5	125	7	2	1100	615	55.84
4	5	125	7	4	900	610	55.70
5	5	140	5	2	989	670	56.52
6	5	135	5	4	900	613	55.74
7	5	140	7	2	1200	683	56.68
8	7	135	7	4	1100	590	55.41
9	7	125	5	2	1150	612	55.73
10	7	120	5	4	810	563	55.01
11	7	120	7	2	812	577	55.22
12	6	125	7	4	850	586	55.33
13	5	120	7	2	800	598	55.53
14	5	140	6	4	1167	610	55.70

15	7	140	7	2	1190	675	56.58
16	6	135	7	4	910	614	55.76
17	6	130	5	3	979	623	55.88
18	6	130	6	5	965	620	55.84
19	4	130	4	3	964	615	55.77
20	6	140	8	5	1208	690	56.77
21	6	120	6	3	800	550	54.80
22	4	140	6	3	1180	671	56.53
23	8	130	6	3	976	620	55.84
24	6	130	6	3	980	598	55.53
25	6	130	6	3	976	617	55.80
26	6	130	6	3	980	628	55.95
27	6	130	6	3	981	630	55.98
28	6	125	6	3	780	593	55.46
29	6	125	6	3	784	594	55.47
30	6	125	6	3	786	593	55.46





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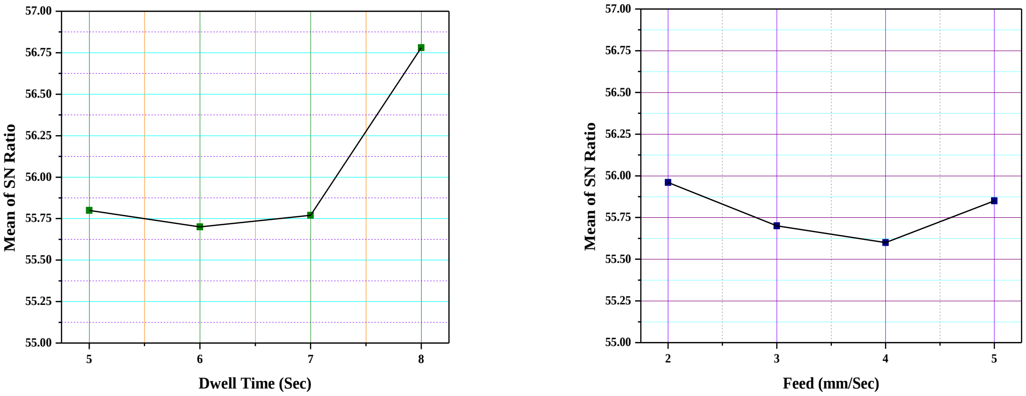

Figure 6: Various Parameters in Main Effect Plot for S/N Ratio (a) Gap in mm (b) Current in Amps (c) Dwell Time in Second and (d) Feed Rate in mm/Sec

The S/N ratio charts for each sample are shown in Figure 6. Each of these variables has been shown as a S/N ratio in the graph above. While current rates have had a significant influence on hardness decline and improvement, dwell time has been shown to be the most important factor in AISI 1045 steel rod hardness improvement [43]. The Induction Borided Process produces high hardness on AISI 1045 steel rods by reducing the spacing, feed rate, dwell time, and current. The Taguchi ideal process parameters are five mm spacing, 140 amps, 2 mm feed rate, and 8 seconds of dwell time.

Validation of Investigated Results

This section compares the induction process with the borided and induction processes. (Both are in table 6). Borided and induction hardened AISI 1045 medium carbon steel was specified for this project. Experiments are used to determine the various hardness levels. It's known that AISI 1040 medium steel [44] can be induction hardened, according to previous research. This study's conclusions are supported by a comparison of the proposed boriding and hardening processes with the actual hardness values. Hardness data in terms of current, feed rate, dwell duration, and so forth are used to validate the indicated outcomes when hardening AISI 1045 steel components using an induction process. After that, we'll compare the new results to the old method that's still in use.

Table 6: Experiment Result of the Borided and Induction Process and the Induction Process

Sl. No	Gap (mm)	Current (Amp)	Dwell time (sec)	Feed rate (mm/s)	Attained temp. (^{0}C)	Hardness of Induction Borided Treated AISI 1045 steel rods 100gm (Hv)	Hardness of Induction Heated Treated AISI 1045 steel rods 100gm (Hv)
1	5	125	5	2	1000	612	601
2	5	140	5	4	1170	630	621
3	5	125	7	2	1100	615	604
4	5	125	7	4	900	610	600
5	5	140	5	2	989	670	653
6	5	135	5	4	900	613	601
7	5	140	7	2	1200	683	661
8	7	135	7	4	1100	590	588
9	7	125	5	2	1150	612	604
10	7	120	5	4	810	563	548
11	7	120	7	2	812	577	550
12	6	125	7	4	850	586	558
13	5	120	7	2	800	598	579
14	5	140	6	4	1167	610	597
15	7	140	7	2	1190	675	658
16	6	135	7	4	910	614	604
17	6	130	5	3	979	623	610
18	6	130	6	5	965	620	608
19	4	130	4	3	964	615	610

20	6	140	8	5	1208	690	672
21	6	120	6	3	800	550	532
22	4	140	6	3	1180	671	655
23	8	130	6	3	976	620	611
24	6	130	6	3	980	598	579
25	6	130	6	3	976	617	606
26	6	130	6	3	980	628	613
27	6	130	6	3	981	630	614
28	6	125	6	3	780	593	575
29	6	125	6	3	784	594	575
30	6	125	6	3	786	593	574

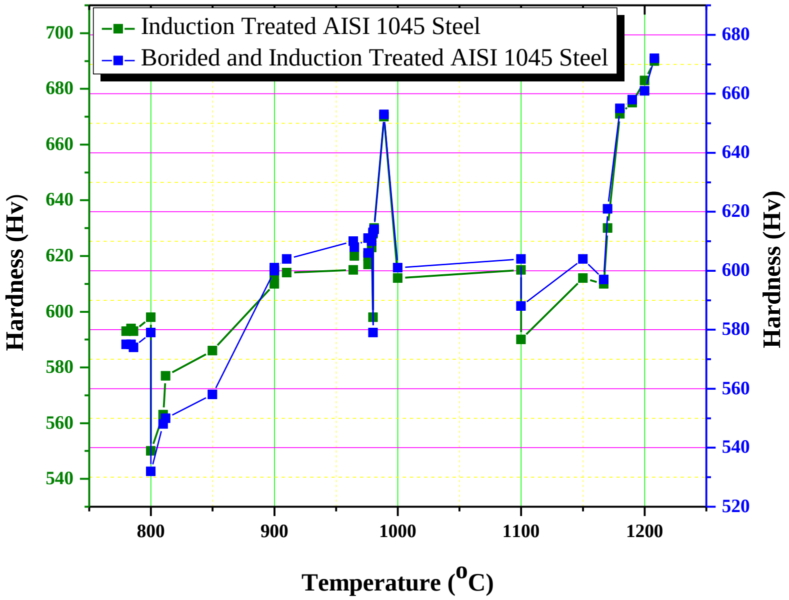

Figure 7: The Process of Verifying Experimental Findings

As seen in Figure 7, our results are confirmed by experimentation. AISI 1045 steel samples that have been borided and hardened are represented visually. The proposed boring and hardening methods on medium carbon steel yielded better and improved results, as seen in the

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graph above. Using the described method, specimens' hardness and strength are enhanced. A more durable material may be produced by boriding rather than hardening alone.

Conclusion

This research evaluated the surface hardness of AISI 1045 carbon steel and found that temperature fluctuations have a tremendous effect on the structure and chemical properties of materials. AISI 1045 steel is hardened and tempered via these procedures to improve its structure and toughness. Taguchi optimization may be used to improve process parameters. The lowest hardness values are obtained between 800 and 810 °C, with a maximum hardness of 690 HV at 1208 °C. When martensite is cooled and tempered, it breaks down into a ferrite-carbide combination. The corrosion resistance and surface hardness of AISI 1045 steel materials increase with increasing temperature, peaking at 430 °C. According to the findings, hardening and tempering AISI 1045 steel at a higher temperature results in a higher surface hardness. Bored and hardened AISI 1045 steel has a higher level of hardness than AISI 1045 steel that has not been hardened. Boriding and induction hardening of AISI 1045 steel rods is a method for hardening the metal. Eventually, researchers may investigate what causes materials to lose their tensile strength after they've been treated. The tensile strength and ductility of AISI 1045 steel may be improved by the use of techniques such as annealing. Hardening, tempering, and quenching are all methods that can be used to make materials better.

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