Check for updates

Induction Heat Treatment of Fasteners: Process Parameters, Temperature Uniformity, and Modeling-Based Optimization — A systematic Review & case study

Rahul Chauhan [1] and N K Chavda [2]

[1] Department of Mechanical Engineering, Gujarat Technological University & B Institute of Technology, V.V. Nagar, Anand, Gujarat, India
[2] Department of Mechanical Engineering, G. H. Patel College of Engineering and Technology, The Charutar Vidya Mandal (CVM) University, Vallabh Vidyanagar, Anand, Gujarat, India
rrchauhan@bbit.ac.in

Abstract. Over the years, induction heating has become a widely used method for heat treating fasteners because it delivers heat quickly and exactly where it's needed. This localized control is critical in a production environment. Heat can be applied to the heads of bolts or threads (or both) in seconds with significantly less energy waste than other methods like furnace heat treating. However, generating a consistent temperature across a threaded part (like a bolt) is much more complicated than it appears. Factors such as the grooves of the threads, the presence of sharp edges near the head of the bolt, and the fact that electromagnetic currents like to be near the surface increase the complexity of heating the part. When an induction coil heats a small steel bolt, there is a noticeable difference in heating rates between different areas of the bolt. This difference in heating rates will lead to differences in hardness or microstructure within the bolt.

Due to these complexities, researchers have been examining the heating of small cylindrical parts (i.e., fasteners) in more detail. Several variables, such as frequency of the excitation source, affect how deeply the induced current will penetrate into the part. Likewise, other factors like power density and time will affect how quickly the surface temperature increases, sometimes before the heat has reached the center.

Keywords: Induction heating; Fasteners; Surface hardening; Temperature uniformity; Coil design; Process optimization

1 Introduction

Although fasteners such as bolts, screws, studs, and nuts typically do not garner much praise on their own, they also carry a significant amount of responsibility on other components. For example, a suspension bolt in an automobile or a structural stud in a steel frame undergoes repeated loading, vibration, and sometimes exposure to harsh external conditions. If either of these components fails, the consequences can be severe. Because of this, the mechanical reliability of these fasteners is strongly dependent on many characteristics including surface hardness, fatigue resistance, wear characteristics, and dimensional stability. Most of these characteristics are not initially provided by the metal but rather develop, or fail to develop, through the heating process of heat treatment [16–19].

© The Author(s) 2026
J. Saxena et al. (eds.), *Proceedings of the International Conference on Sustainable Micro-Nano Materials & Innovative Technology (ICSUMMIT 2026)*, Atlantis Highlights in Engineering 44,
https://doi.org/10.2991/978-94-6239-727-9_29

Induction heating has been gaining popularity as the preferred method of heat treatment for many of these types of fasteners. [30–33]. The advantages of induction heating are clear. Induction heating allows components to be heated in seconds (mainly only at the areas that require hardening) compared with conventional ovens and typically results in much lower energy loss during the process and is more compatible with modern production lines. [42,43]. However, despite the clear advantages, the process is far more complicated than what is described in textbooks. Achieving a uniform temperature profile in a threaded fastener is very difficult due to the interruption of the thread geometry along the length of the fastener. It is also extremely difficult to achieve a uniform temperature profile at the underside of the head and at the shoulder of the fastener [22,26].

Table 1. Typical industrial applications of induction heating for fasteners and small components (compiled from Refs. [2–5, 8, 10]).

Process	Purpose	Temperature range	Notes
Surface hardening	Wear & fatigue resistance	800–950 °C	Rapid heating & quenching
Tempering	Reduce brittleness, stabilize structure	150–650 °C	Lower power, longer hold
Band annealing	Stress relief after cold forming	550–700 °C	Local, controlled heating
Solution/precipitation heat treatment	For alloy/stainless fasteners	Material-specific	High precision required

Fig1. Schematic of an induction heating system

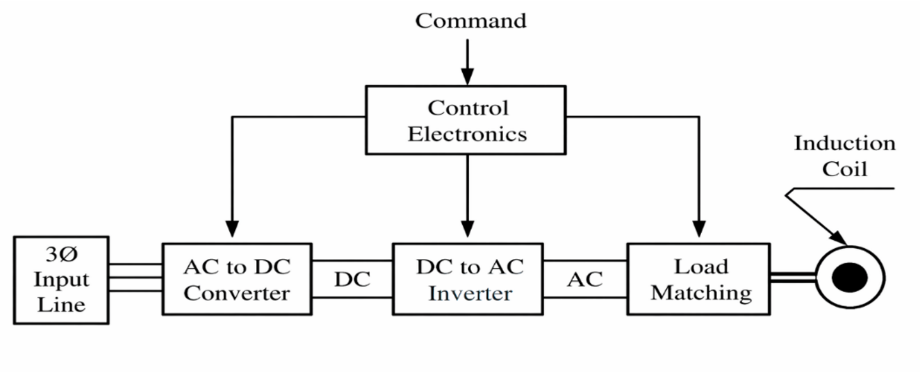


Fig 2. Block diagram of induction heating process

Fig 3. Typical industrial induction billet heating system (75 kW, 10 kHz), commonly used in forging and heat-treatment applications

Induction billet heater systems are used in various industrial processes, such as steel production, forging, and heat treatment. They utilize electromagnetic induction to heat billets (small, rectangular blocks of metal) efficiently and uniformly.

A 75 kW/10 kHz induction billet heater system is a specific type of induction heating system used for heating billets (small, rectangular blocks of metal) in various industrial processes. Here are some key points about this system:

- Power output: 75 kW (kilowatts)
- Frequency: 10 kHz (kilohertz)- Type: Induction heating system

- Application: Heating billets in various industrial processes such as steel production, forging, and heat treatment

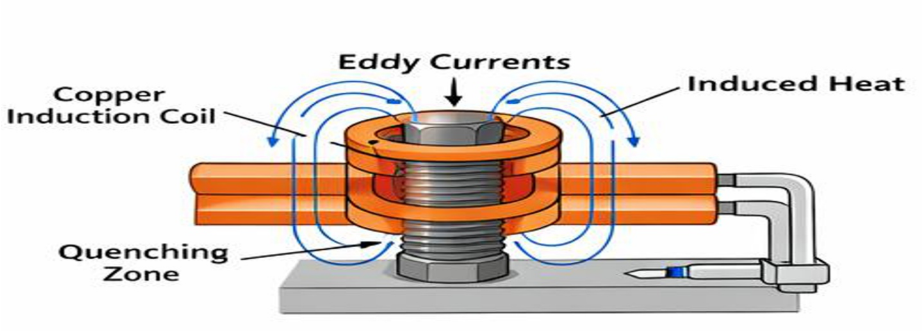


Fig4. Schematic illustration of coil–fastener arrangement highlighting electromagnetic coupling and geometric effects during induction heating

3. Influences on Process Variables

Usually, when having uniform heating during induction heating there isn't just one setting that gives you uniformity on the machine. Usually many of the process variables are required to work together, and sometimes they don't work together, in making up the total temperature profile. Many times, engineers will find that changing a variable to correct one area creates an issue in another area. Therefore it can be just as important to understand how the process variables interact with each other, as it is to understand what each process variable does in an individual manner **[1,2,3,4].**

3.1 Frequencies used for excitation

How deep the induced currents penetrate into the material, and therefore how much heat is transferred throughout the workpiece is primarily dependent upon the frequency used to excite the workpiece **[12,18]**. Higher frequencies typically result in a location of heat closer to the surface. For example, for threaded components, the peaks of the threads are usually heated faster than the bottoms or roots of the threads **[17,18]**. You can think of a bolt in an induction coil, using a high frequency of excitation, the sharp ridges should ignite first before the valley regions; therefore, creating localized areas of extreme heat instead of a uniform temperature field.Lower frequencies penetrate the current deeper into the material; therefore, they will produce a greater depth of penetration into the material. However, sometimes depth of penetration may result in less than anticipated improvements [22,26].

4. Critical Review of Experimental and Numerical Studies

Table 2. Summary of representative review and research articles on induction heating.[22], [26], [28], [29], [30], [33], [35], [37]

Study	Component geometry	Method	Key findings	Validation level	Limitation for fasteners
Rathinasuriyan et al. (2023)	Smooth EN8 rods	Experimental	Improved hardness with optimized power	Hardness only	No threaded geometry
Yamaç et al. (2023)	AISI 4340 cylinder	FEM + exp.	Coil geometry improves uniformity	Partial	Axisymmetric model
Shi et al. (2024)	Camshaft	3D FEM	Improved axial uniformity	Numerical	Not fastener-scale
Gao et al. (2020)	Spot heating	Experimental	Feed path affects hotspots	Thermal only	No metallurgical data

Critical Assessment:
Most studies rely on simplified geometries and indirect validation metrics such as hardness. Thread-level electromagnetic concentration and axial end effects relevant to fasteners are rarely addressed experimentally. Numerical predictions often overestimate achievable temperature uniformity due to geometric simplifications **[11,13,37]**.

Table 3. Summary of representative studies on optimization of induction heating parameters

Ref. No.	Authors	Objective	Input Parameters	Output Parameters	Methodology / Technique	Published Source
1	Jakubovičová *et al.*	Optimization of induction heating process to achieve uniform surface temperature	Current (A), frequency (Hz), heating time (s), inductor size (m), initial temperature (K), model length	Material density, specific heat, thermal conductivity, electrical resistivity, relative permeability	Numerical modeling using Euler method and geometrical optimization	*Procedia Engineering*, Elsevier, Vol. 136 (2016) 125–131

Ref. No.	Authors	Objective	Input Parameters	Output Parameters	Methodology / Technique	Published Source
2	Li *et al.*	Investigation of synergistic effects of induction heating parameters on heating efficiency	Heating depth, current, frequency	Temperature variation and uniformity	Taguchi method, analysis of variance (ANOVA), Response Surface Methodology (RSM)	*Applied Sciences*, Vol. 13 (2023) 555
3	Kohli & Singh	Optimization of processing parameters in induction hardening	Feed rate (mm/s), dwell time (s), current (A), coil–workpiece gap (mm)	Hardness in rolled and normalized material conditions	ANOVA and Response Surface Methodology (RSM)	*Sādhanā*, Vol. 36, No. 2 (2011) 141–152
4	Metage & Sidhu	Optimization of process parameters in induction hardening of 41Cr4 steel	Power (kW), feed rate (mm/s), dwell time (s), quench flow rate (L/min)	Case hardness (HRC), effective case depth (mm)	Response Surface Methodology (RSM)	*International Journal of Mechanical Engineering Research*, Vol. 7, No. 2 (2017) 83–97

Table 4. Additional representative studies on induction heating system design and parameter optimization

Ref. No.	Authors	Objective	Input Parameters	Output Parameters	Methodology / Technique	Published Source
5	Durukan	Investigation of induction heating parameters on forging billet temperature	Coil power, conveyor speed, coil box hole diameter	Resultant billet temperature	Factorial design of experiments (2^3 DOE) and multiple linear regression	M.Sc. Thesis, Middle East Technical University, Turkey

Ref. No.	Authors	Objective	Input Parameters	Output Parameters	Methodology / Technique	Published Source
6	Limon Leyva *et al.*	Parametric optimization of inductor design for heating metallic materials	Number of coil turns, turn separation (mm), coil size (mm), supply voltage (V), heating time	Temperature (°C), current consumption (A)	Design of experiments (DOE), Response Surface Methodology (RSM), analysis of variance	*Preprints.org*, 2024 (not peer-reviewed), doi:10.20944/preprints202410.1813.v1
7	Baldan *et al.*	Development of hierarchical optimization approaches for surface hardening induction systems	Heating time (s), frequency (kHz)	Hardening depth	Hierarchical and multi-objective optimization	Proc. 9th Int. Symp. on Electromagnetic Processing of Materials (EPM 2018)
8	Scepanskis & Geza	Evaluation of simulation software in induction heat treatment	Induction coil design, process parameters	Cost reduction, time efficiency, process effectiveness	Numerical simulation using CENOS software	CENOS Platform (Industrial application report)
9	Karpushkin *et al.*	Modeling of induction heating devices for vulcanization press platens	Inductor power, heat-transfer coefficient	Heating time with ±10% accuracy	Finite integral transformation method and thermal calculation	*Transactions of TSTU*, Vol. 17, No. 1 (2011)
10	Fang *et al.*	Parameter optimization and prediction modeling for induction heating of large-diameter pipes	Current, frequency, current density (A/m²), air gap (mm)	Outer-wall and inner-wall temperature (°C)	Orthogonal test design and linear regression modeling	*Mathematical Problems in Engineering*, Hindawi, 2018, Article ID 8430578

Table 5. Additional studies on numerical modeling, optimization, and induction-assisted heating processes

Ref. No.	Authors	Objective	Input Parameters	Output Parameters	Methodology / Technique	Published Source
11	Kranjc *et al.*	Optimization of induction heating process using numerical modeling and evolutionary algorithms	Coil position, excitation current amplitude, frequency	Target temperature distribution	Numerical modeling coupled with genetic algorithm optimization	ResearchGate preprint, 2014
12	Heinrich	Analysis of efficient excitation frequency in induction heating systems	Excitation frequency	Longitudinal and transverse magnetic flux heating behavior	Finite Element Method (FEM) simulations	Technische Universität Wien (Doctoral research)
13	Hirono *et al.*	Design optimization of primary core in induction heating rolls	AC current, material volume	Heating rate, surface temperature uniformity	2D level-set method combined with 3D coupled magnetic–thermal FEM	*IEEJ Journal of Industry Applications*, Vol. 7, No. 1, pp. 64–72
14	Wang & Zhang	Characterization and optimization of temperature field distribution in electromagnetic induction-based pipe lining processes	Frequency, travel speed, coil-to-workpiece gap	Temperature fluctuation of lining layer	Response Surface Methodology (RSM)	Elsevier journal (Science Direct)
15	Liu *et al.*	Finite element investigation magnesium alloy internal threads	Hole diameter, machine speed, heating temperature	Thread deformation layer, strength and hardness improvement	Finite Element Analysis (FEA)	*Materials*, 13 (2020) 2170

4.1 Experimental Investigations

Much of the experimental research on induction heating has concentrated primarily on determining quantitative values that could be measured after the heat treatment, such as hardness distribution and case depth. These parameters are feasible to analyse and relatively easy to measure. For instance, in one experimental procedure, a steel sample is heated and then cut into sections, and the hardened layer is subjected to microscopy. This technique allows for a good comparison of different process conditions. One of the most significant limitations of the experimental results is that the samples used in these types of experiments are typically cylindrical bars and not actual threaded fasteners. Although this simplification makes it relatively easy to control the setup for experimentation, one must ponder how accurately it reflects the true geometry of real components. The presence of threads creates additional ridges, valleys, and abrupt changes in geometry that can modify the electromagnetic field in subtle ways. In comparison, a smooth rod exhibits predictable behaviour throughout the coil.

Another area of concern is measuring temperature. In most laboratory studies, temperatures are typically taken only on the surface of the sample (via either infrared sensors or thermocouples) and usually near the outer surface. This technique is logical because of the difficulty in obtaining internal temperature readings while performing rapid induction heating experiments. However, by taking only surface measurements, the researcher cannot fully appreciate the complete structure of heat distribution because the internal heat distribution may be significantly different than what is measured on the surface of the sample, especially when the parts being analyzed possess complex geometries, such as bolts and studs.**[22], [26], [35],[38].**

4.2 Some Testing Has Been Carried out in Industry

Fig 5. Hardness Testing Machine

Fig 6. Mechanical Testing Setup

Fig 7. Hardness Testing Setup

Sample:1	Nut Test Piece
Identification of Sample	M27 Nut (Class 8); Lot B1
Material Specification	IS 1367(PART 6):2018 Property Class 8

Discipline : Mechanical, Group : Mechanical Properties of Metals
Proof Load Test

Test Method : IS 1367-6:2018

Equipment : CTM-200T Cal. Dt: 20-Feb-2024 Due DI.: 19-Feb-202S

Sr.no	Parameter	Obtained Value	Requirement Value
1	Proof Load Heavy Hex	422300	422300 min.

Remark: The above result(s) meets the specified requirements of IS 1367 (Part 6):2018 Property Class 8 with respect to test(s) carried out.

Sample:2	Nut Test Piece
Identification of Sample	M27 Nut (Class 8); Lot B1
Material Specification	IS 1367(PART 6):2018 Property Class 8

Discipline : Mechanical, Group : Mechanical Properties of Metals

HARDNESS TEST

Test Method : IS 1586-1:208

Equipment : HTM-1 Cal. DI: 05-May-2024 Due Dt.: 04-May-2025

Brinell Hardness Value	Reading 1	Reading 2	Reading 3	Average	Requirement At Surface
	237	240	237	237.33	233-353

Remark: The above result(s) meets the specified requirements of IS 1367 (Part 6):2018 Property Class 8 with respect to test(s) carried out

Sample:3	**Nut Test Piece**
Identification of Sample	M27 Nut (Class 8); Lot B1
Material Specification	IS 1367(PART 6):2018 Property Class 8

TEST REPORT
Discipline : Mechanical, Group : Mechanical Properties of Metals
HARDNESSTEST
Test Method : IS 1MAI-1:2019
Equipment : HTM-1
Remark: The above result(s) meets the specified requirements of IS 1367 (Part 6):2018 Property Class 8 with respect to test(s) carried out.

Vickers Hardness Value (HV)	**Reading 1**	**Reading2**	**Reading3**	**Average**	**Requirement**
1) At Surface	238	242	239	239.67	233-353
2) At Surface	237	235	238	236.67	233-353
3) At Surface	240	242	245	242.33	233-353
4) At Surface	243	238	240	240.33	233-353
5) At Surface	245	240	241	242.00	233-353

Sample:4	**Test Piece**
Identification of Sample	B16 Round Bar-200 mm length
Material Specification	ASTM A193/A193M-2023 Grade B16

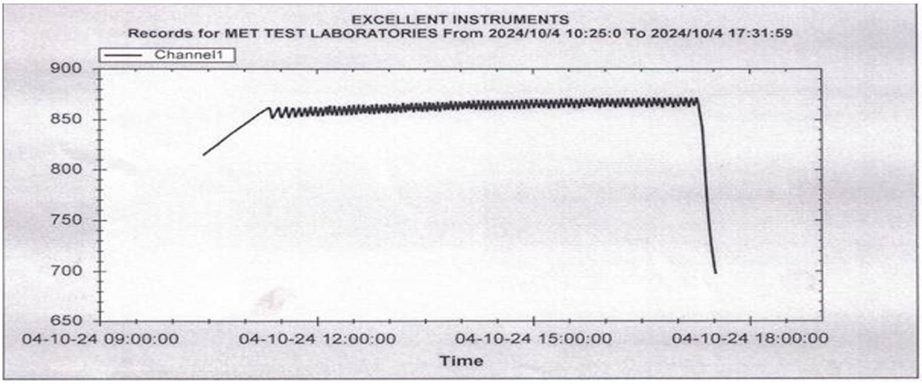
TEST REPORT
Discipline : Chemical, Group : Metals and Alloys Spectro Chemical Analysis
Test Method : IS 8811:1998(RA2018)
Equipment :SPM-2

Element	**Result**	**Requirement**
% Carbon	0.407	0.36-0.47
% Manganese	0.513	0.45-0.70
% Phosphorus	0.0159	0.035 max.
%Sulphur	0.0069	0.040 max.
%Silicon	0.251	0.15-0.35
%Chromium	0.894	0.80-1.15
%Molybdenum	0.516	0.50-0.65
%Vanadium	0.284	0.25-0.35
%Aluminium	0.009	0.015 max.

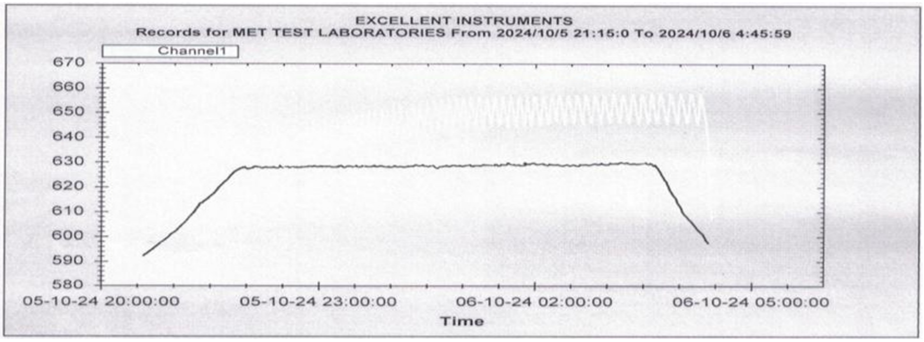
Sample:5	Test Piece
Identification of Sample	B16 Round Bar-200 mm length
Material Specification	ASTM A193/A193M-2023 Grade B16

Discipline : Mechanlcal. Group: Mechanical Properties of Metals
TENSILE TEST
Test Method : ASTM A370:Z023
Equipment : UTM-1

Test Parameters	Result	Requirement
Diameter (mm)	12.48	
Cross- sectional area (mm*)	122.33	
Original gauge length (mm)	50	
0.2% Proof load (N)	103491	
0.29a Proof strength (N/mm*)	846.00	725 min
Ukimate tensile load (N)	119643	
U.T.S (N/mm’)	978.03	860 min
Final gauge length (mm)	61.07	
Elongation (36)	22.14	18 min
Final diameter (mm)	7.23	
Reduction of area (%)	66.44	50.00 min
Result	Satisfactory	



- The figure presents the results of the hardening test conducted at a temperature of 860 °C for a duration of 6 hours."



- The figure presents the results of the tempering test conducted at 630 °C for a duration of 6 hours."

5. Numerical Modeling and Temperature Uniformity

Most researchers will attempt to understand how the heat spreads throughout an object via numerical modeling. In general, numerical modeling will combine electromagnetic and thermal calculations so that the model is able to create an accurate representation of both how the induced currents are generated by the magnetic field and how the temperature increases in the material due to the generated heat. Theoretically, this can be depicted as; Generated magnetic field produces induced current, which then produces generated heat, and the generated heat causes the material to have different properties based upon its temperature, and finally, the material will create a different generated field due to the change in material properties. Therefore, this whole process continuously feeds into all of the previous elements.

The difficulty with this entire process is that the electrical resistivity, magnetic permeability, and thermal conductivity of the material do not stay the same as the temperature of the material rises. As an example, the way that steel behaves when it is at room temperature is much different than when it is very close to / at the austenitizing temperature range. If the model does not take these changing properties of the material into play, the simulation results will quickly move away from reality. Because of this, the majority of all accurate simulations/models will use material properties that are temperature variable, even though they may be more complex and time-consuming to calculate.

The geometry of the object (geometry introduces additional complexity) adds to the amount of time necessary to model and simulate; for example, threaded fasteners have tight grooves and repeating ridges, and they create a very complicated electromagnetic environment for the model to calculate and simulate. If all aspects of the geometry are modeled (i.e. small detail, threads, grooves, dihedral angles, etc.), a very fine computational mesh is required, which very quickly creates extremely long simulation times. For this reason, most [8,11,12,22,37].

6. Microstructural and Mechanical Property Outcomes

The role uniform heating plays during heat treatment is quiet yet significant in determining how steel transforms. When heat is applied uniformly across the surface and near-surface of the part being heated, the martensitic transformation is more likely to occur uniformly. A hardened layer will also form at a reasonably predictable depth; thus, the hardness profile from one area of the part to another will be relatively similar and stable. So, an adequately heated fastener will have similar hardness readings whether measured at or near the thread crest or slightly deeper into the root.

Heating inconsistently makes achieving this kind of uniformity much more difficult. For example, local hot spots or cold spots can disrupt the transformation process. One area of the part may achieve austenitizing temperature while some other area has not reached it, and the temperature difference may only be tens of degrees. Still, this difference may cause case depth or hardness distribution to be different than it otherwise would. The effects of inconsistent heating differences become exacerbated in threaded components due to the fact that the geometry of threads creates natural stress concentrations. Furthermore, the potential for additional localized stresses will occur at the transition between crest and root when stress is applied to the thread (including during heat treatment). [34,46,47,48,52].

Table 6. Microstructural and Mechanical Property Outcomes

Parameter	Effect on properties
Heating uniformity	Controls case depth & hardness distribution
Quenching conditions	Residual stress & distortion
Tempering	Fatigue strength & toughness
Surface condition	Influences corrosion & coating behaviour

7. Research Gaps

There are many problems with the current body of research that cannot be overlooked. First, current research shows that there are very few instances of detailed modeling of geometries with threading. Most of the current simulations use smooth, simplified geometries, as they are easily computable; however, this decision is acceptable due to the nature of numerical computations and the fact that anyone who has handled bolts or studs can attest that there are small-ridges and valleys introduced by the thread profile that will not behave like a smooth cylinder inside a coil when subjected to induction heating. The simplification of these geometries increases the speed at which the model can run, but likely restricts the investigation of some of the more interesting thermal behavior.

Another problem with validating experimental evidence; laboratory tests only confirm the hardness/case depth of the fastener after the fact, which does tell us something about the end result of the treatment process. However, there is still no way to truly observe what is happening inside of a small fastener while it is rapidly heating, they are essentially still a black box. Observing directly what is occurring inside the fastener will be difficult due to sensor interference with the electromagnetic field and most of the non-contact measurements will only capture surface temperatures; therefore, many of the models appear to be ahead of the experimental evidence supporting the models.

Another area in which development has been slow is in real-time temperature measurement. In an industrial heat treatment process, fasteners can be processed very quickly through the system.

8. Research Framework for Fastener-Scale Induction Heat Treatment

Going forward, it would seem necessary to combine experimental studies and numerical or computer model studies much more so than they currently are; that is, they now exist as two separate and distinct areas of research, with both having their own advantages and disadvantages, and questions that remain unanswered by either method individually. On one hand, numerical models allow one to explore the influence of numerous parameters on a rapid basis, thus assisting one in understanding how coil configuration and/or frequency might affect the heating of the specimen. On the other hand, empirical testing of the sample provides the necessary experimental data to validate the numerical predictions.

Testing will be performed on different types of specimens over time. For example, the initial specimen used in most studies will be a smooth cylindrical specimen. This makes sense because from both production and modeling perspectives, it is a relatively easy item to create and will tend to behave predictably when inductively heated. However, the actual components of a product manufactured using induction heating (e.g. in industry) are not typically designed in such a simplistic manner, and by gradually increasing the geometric complexity of the specimen (e.g. from smooth cylindrical specimens to fully-threaded bolted or stud type samples), it is likely that further important elements of inductive heating will be determined that cannot be discovered in a simplified specimen type.

In addition to changing specimen geometric configurations, also critical to the success of testing will be the effectiveness of the experimental design used to generate data. Therefore, rather than altering one parameter at a time, developing structured experimental designs would assist researchers in identifying the effects of multiple variables simultaneously. [8,13].

9. Conclusions

The induction heating of fasteners heavily depends on several process parameters. The key parameters include frequency, power density, and coil design. When one of these parameters is altered, the temperature distribution in a fastener can change, in sometimes unexpected ways. For example, a small difference in frequency could cause heat to be concentrated more on the crests of the threads rather than the roots of the threads. The temperature change in a smooth laboratory specimen might seem small, but for a bolt, these subtle differences may be significant.

The geometry of fasteners is another factor to consider. Especially when they have threads, fasteners have extreme changes in geometry, many narrow valleys and repeating ridges which change the way the fasteners interact with the electromagnetic field (EMF). In a perfectly smooth, round metal cylinder the induction field is quite gentle to the cylinder. In a threaded stud, the field has less respect for the physical boundaries of the fastener, and the temperature distribution across the fastener's surface will also be nonuniform. This difference between the experimentally defined (idealized) geometry of fasteners and actual geometries can often be difficult to identify in simulation-based analyses.To bridge this gap more experimental validation could be beneficial to the field. While modeling of fasteners is valuable, it gives an insight into the trend and helps narrow the search for acceptable parameters.

10. References

1. Jakubovičová L, Beniak J, Kováčiková P, Vaško M. Optimization of induction heating process to achieve uniform surface temperature. **Procedia Eng.** 2016;136:125–131. https://doi.org/10.1016/j.proeng.2016.01.195
2. Li X, Zhang Y, Chen Z, Wang H. Investigation of synergistic effects of induction heating parameters on heating efficiency using statistical methods. **Appl Sci.** 2023;13:555. https://doi.org/10.3390/app13010555
3. Kohli S, Singh R. Optimization of processing parameters in induction hardening using response surface methodology. **Sādhanā.** 2011;36(2):141–152. https://doi.org/10.1007/s12046-011-0014-7
4. Metage M, Sidhu BS. Optimization of process parameters in induction hardening of 41Cr4 steel. **Int J Mech Eng Res.** 2017;7(2):83–97.
5. Durukan O. Investigation of induction heating parameters on forging billet temperature. Master's Thesis, Middle East Technical University; 2016.

6. Limon Leyva A, Hernández Martínez E, Rodríguez Hernández J. Parametric optimization of inductor design for heating metallic materials. **Preprints.** 2024. https://doi.org/10.20944/preprints202410.1813.v1
7. Baldan A, et al. Hierarchical optimization approaches for surface hardening induction systems. In: **Proc 9th Int Symp Electromagn Process Mater (EPM 2018)**; 2018.
8. Scepanskis M, Geza V. Evaluation of simulation software in induction heat treatment. **CENOS Industrial Application Report**; 2019.
9. Karpushkin A, et al. Modeling of induction heating devices for vulcanization press platens. **Trans TSTU.** 2011;17(1):1–9.
10. Fang Z, Liu Y, Zhang H. Parameter optimization and prediction modeling for induction heating of large-diameter pipes. **Math Probl Eng.** 2018;2018:8430578. https://doi.org/10.1155/2018/8430578
11. Kranjc M, et al. Optimization of induction heating process using numerical modeling and evolutionary algorithms. **ResearchGate Preprint**; 2014.
12. Heinrich M. Analysis of efficient excitation frequency in induction heating systems. PhD Dissertation, Technische Universität Wien; 2013.
13. Hirono T, et al. Design optimization of primary core in induction heating rolls using coupled FEM. **IEEJ J Ind Appl.** 2018;7(1):64–72. https://doi.org/10.1541/ieejjia.7.64
14. Wang Y, Zhang L. Characterization and optimization of temperature field distribution in electromagnetic induction-based pipe lining processes. **Elsevier (ScienceDirect)**.
15. Liu Y, et al. Finite element investigation of electromagnetic induction-assisted extrusion of magnesium alloy internal threads. **Materials.** 2020;13:2170. https://doi.org/10.3390/ma13092170
16. Rudnev V, Loveless D, Cook R, Black M. *Handbook of Induction Heating*. 2nd ed. Boca Raton: CRC Press; 2017.
17. Davies EJ. *Conduction and Induction Heating*. London: IEE Press; 1990.
18. Zinn S, Semiatin SL. *Elements of Induction Heating*. ASM International; 1988.
19. Lupi S, Forzan M, Aliferov A. *Induction and Direct Resistance Heating*. Springer; 2015.
20. Totten GE, Howes MAH, Inoue T. *Handbook of Residual Stress and Deformation of Steel*. ASM; 2002.[21] Herring DH. Induction hardening fundamentals. *Ind Heat Treat*. 2014;20(3):12–18.
21. Yamaç E, et al. Effect of coil geometry on induction heating uniformity. *J Mater Process Technol*. 2023;317:117926.
22. Jakubovičová L, et al. Optimization of induction heating process to achieve uniform surface temperature. *Procedia Eng*. 2016;136:125–131.
23. Lupi S. Inductor design for surface heat treatment. *Heat Treat Met*. 2012;39(4):101–108.
24. Sahay SS, et al. Influence of air-gap on induction heating efficiency. Mater Today Proc. 2020;26:3021–3025.
25. Kranjc M, et al. Optimization of induction heating using numerical modeling. Appl Therm Eng. 2016;100:477–489.
26. Scepanskis M, Geza V. Evaluation of simulation software in induction heat treatment. Procedia Manuf. 2019;36:189–196.
27. Fang Z, et al. Parameter optimization for induction heating of pipes. Math Probl Eng. 2018;2018:8430578.
28. Liu Y, et al. FEM investigation of induction-assisted extrusion of internal threads. Mater. 2020;13:2170.
29. Neu RW, et al. Fatigue behavior of threaded fasteners. Int J Fatigue. 2014;68:63–74.
30. Pilkey WD, Pilkey DF. Peterson's Stress Concentration Factors. Wiley; 2008.
31. Stephens RI, et al. Metal Fatigue in Engineering. Wiley; 2001.

32. Bickford JH. An Introduction to the Design and Behavior of Bolted Joints. CRC Press; 2007.
33. ISO 898-1:2013. Mechanical properties of fasteners.
34. Gao X, et al. Hot spot formation during induction spot heating. J Mater Process Technol. 2020;276:116411.
35. Li X, et al. Synergistic effects of induction parameters. Appl Sci. 2023;13:555.
36. Wang Y, Zhang L. Optimization of temperature field in induction processes. J Manuf Process. 2021;64:398–409.
37. Song J, et al. Real-time temperature monitoring in induction heating. Measurement. 2022;187:110321.
38. Sun J, et al. Closed-loop control of induction heating. Control Eng Pract. 2020;95:104242.
39. Totten GE, Funatani K, Xie L. Handbook of Mechanical Alloy Design. CRC; 2004.
40. Herring DH. Distortion control in heat treatment. Heat Treat Met. 2011;38(2):35–42.
41. Rudnev V. Energy efficiency of induction heating systems. Ind Heat. 2018;54(4):18–25.
42. Lupi S, et al. Energy benchmarking of induction systems. Appl Energy. 2016;169:799–807.
43. CENOS Platform. Industrial induction heating case studies. 2022.
44. EPRI Report. Industrial induction heating applications. 2019.
45. Bhadeshia HKDH. Martensite and bainite in steels. Metall Mater Trans A. 1999;30:739–744.
46. Withers PJ, Bhadeshia HKDH. Residual stress in heat treated steels. Mater Sci Technol. 2001;17:366–375.
47. ASM Handbook, Vol. 4A. Steel Heat Treating Fundamentals and Processes. ASM International; 2013.

Open Access This chapter is licensed under the terms of the Creative Commons Attribution-NonCommercial 4.0 International License (http://creativecommons.org/licenses/by-nc/4.0/), which permits any noncommercial use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license and indicate if changes were made.

The images or other third party material in this chapter are included in the chapter's Creative Commons license, unless indicated otherwise in a credit line to the material. If material is not included in the chapter's Creative Commons license and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder.