

Original Article

Enhancing the Mechanical Properties of CI200 Casting through Process Parameter Optimization

Mohnesh Mandhre¹, Sachin Ghalme²

¹Department of Mechanical Engineering, Pravara Rural Engineering College, Savitribai Phule Pune University, Maharashtra, India.

²Department of Mechanical Engineering, Sandip Institute of Technology and Research Centre, Savitribai Phule Pune University, Maharashtra, India.

¹Corresponding Author : mdmscoea@gmail.com

Received: 04 March 2026

Revised: 05 April 2026

Accepted: 07 May 2026

Published: 27 June 2026

Abstract - CI200 grade cast iron is widely used in industry; however, it cannot be used in very high-stress applications since it is brittle, has low impact toughness, and has a maximum tensile strength of 200 MPa. An examination of the literature shows that there are several ways to improve the mechanical properties of cast iron. The combined impacts of a magnetic field during the solidification process, the inclusion of copper powder in the ladle, and variations in shake-out duration have not been jointly studied, making this experimental inquiry both original and noteworthy. The Taguchi L9 orthogonal array was used to plan the tests and improve the settings for the casting process. Experimental investigation included microstructural analysis and mechanical testing, such as hardness, tensile strength, and impact tests. The Experimental work also used ANOVA analysis to find out how important the process parameters were. The results show that the magnetic field has the greatest effect on the mechanical properties of CI200. The process parameters were optimized to find the best conditions for achieving the desired mechanical qualities. Adding copper also helps the formation of pearlite, which makes the material stronger, and shake-out time makes it tougher. The optimal conditions for achieving the desired mechanical qualities were a magnetic field of 6000 gauss, a shake-out time of 7200 seconds, and a copper content of 1.0 weight %. These three factors together increased the mechanical properties.

Keywords - Anova analysis, CI200 Cast Iron, Copper alloy, Magnetic field casting, Taguchi method.

1. Introduction

Cast iron is widely utilized in engineering and industrial sectors because of its excellent castability, cost-effective manufacture, and satisfactory mechanical qualities [1]. Grey cast iron, particularly CI200, is favored for its microstructure, including graphite particles, which confer benefits like excellent castability, wear resistance, and vibration-dampening properties. Nonetheless, these graphite flakes function as stress concentrators, diminishing tensile strength and impact resistance, resulting in more defects compared to other cast iron grades, hence restricting their employment in scenarios involving elevated mechanical stresses [3]. The characteristics of cast iron are intricately linked to its microstructure, which is predominantly influenced by the solidification process and the incorporation of alloying elements. In the casting process, factors such as pouring temperature, cooling rate, and mould conditions affect heat transmission and phase change [4]. Specifically, variables such as cooling rate, mould thickness, and shake-out duration significantly influence graphite morphology and matrix structure, which eventually impact mechanical qualities such

as strength and hardness [3, 5, 16]. Diverse procedures have been devised to enhance the performance of cast iron; refining and processing techniques have been employed to reduce impurities and improve structural regularity, resulting in superior mechanical properties [6-8]. Moreover, electromagnetic and magnetic field-assisted casting techniques have been investigated to regulate molten metal flow and solidification properties [9, 10]. The utilization of a rotating magnetic field has been shown to polish the microstructure, enhance homogeneity, and diminish casting flaws, consequently improving overall performance.

Alloying is a prevalent method employed to enhance the characteristics of cast iron material. Copper is a significant alloying metal that facilitates the development of a pearlitic matrix, thereby improving its strength and hardness. The copper content must be meticulously regulated, as more than 2% can adversely impact the material's mechanical qualities. [1, 15, 17]. Excessive pearlite content may diminish impact hardness. Silicon and vanadium have also been employed to alter the morphology of graphite and the properties of the



matrix. For instance, the incorporation of ferrosilicon enhances the refinement of graphite structure and optimizes the equilibrium between hardness and toughness but potentially elevates costs and occasionally diminishes strength [11-13]. In addition to casting and alloying methods, post-processing techniques have been utilized to enhance surface and bulk characteristics. Techniques like laser surface treatment have demonstrated the ability to improve hardness and wear resistance [2, 17]. Moreover, research on ductile and austempered cast irons demonstrates that microstructural characteristics, including ferrite-pearlite ratio, nodularity, and graphite shape, significantly affect mechanical properties [18-21]. These findings demonstrate the importance of regulating the microstructure to attain enhanced mechanical properties. Prior research has documented numerous techniques to improve the mechanical characteristics of various grades of cast iron and other metallic substances.

Alloying methods, especially the incorporation of copper, have been extensively employed in cast iron to improve pearlite phase production, leading to alterations in mechanical properties. Furthermore, it has been shown that the process parameters, such as shake-out time, influence the cooling rate and the distribution of the residual stresses. Researchers have mainly focused on these methodologies separately, however, and their synergies have not been studied extensively. The effects of magnetic field, copper addition, and shake-out time have been studied in the past individually.

These parameters will be studied together to gain an understanding of the combined effect on CI200 grade cast iron. The studies used the Taguchi method of simultaneous vary of all three parameters and allowed for the systematic study of parameter interactions. The method used was to apply a magnetic field from 0 to 6000 gauss during solidification, adjust the copper content, and the shake-out duration. Such a detailed analysis of these characteristics together gives a better understanding of their effect on graphite morphology, pearlite production, and the overall mechanical properties, which cannot be obtained by analyzing them separately.

2. Materials and Methods

The CI200 grade cast iron was selected as the base material for samples, and high-purity pig iron and steel scrap were used for melting.

Table 1. Chemical composition of CI200 material

Material	Weight %
Carbon	3.5
Silicon	1.8
Manganese	0.6
Phosphorous	0.2
Sulphur	0.1
Iron	93

3. Experimental Methodology

In this work, the Taguchi method is a statistical method used to optimize the casting process parameters with fewer experiments. The Taguchi technique uses an L9 orthogonal array to scientifically evaluate the effect of different parameters on the output responses and thus minimize the effort, expenses, and material usage. This approach provides a fast and powerful tool to identify important process parameters and their optimum combinations as opposed to a full factorial design. An array of L9 was used in this study, which required three control parameters, each at three levels. The choice of the L9 array is justified because it can ensure statistical reliability, greatly reduce the complexity of the experiments, and capture the main effects of the process factors with only nine experiments.

Data were analyzed using experimental design, Analysis of Variance (ANOVA), and regression modeling, and response optimization was carried out using Minitab 21. This software was used for the evaluation of the significance of the factors of input and to determine optimum casting conditions for the improvement of mechanical properties. It is assumed that the magnetic field is homogeneous throughout the mould cavity because the permanent magnet configuration is designed to provide a uniform magnetic field in the mould pouring area. It is a common practice in analogous experimental studies to make this assumption so that analysis is simplified, but not significantly reduced in accuracy.

3.1. Selection of Process Parameters and Levels

A literature search and practical considerations in cast iron processing led to the identification of three critical process parameters. The selected process parameters were magnetic field intensity (0, 3000, and 6000 gauss), shake-out duration (3600, 5400, and 7200 seconds), and copper concentration (0.5, 1.0, and 1.5 weight %). The range of magnetic field intensities (0 to 6000 gauss) was sufficient to ensure a measurable influence on the molten metal flow and solidification behavior, which did not cause instability in the casting process. The amounts of copper added were determined because of its known role in promoting the formation of pearlite and enhancing the mechanical properties of cast iron. High-quality electrolytic copper powder (99.9% purity), according to the industry standard, was added to the molten metal. The particle size of copper powder was maintained at 50-150 μm to ensure fast melting of the copper powder and uniform distribution within the molten cast iron. The above-mentioned amounts of copper (0.5, 1.0, and 1.5 wt. %) were carefully weighed on a digital balance of accuracy ± 0.01 g, and added to the molten metal before pouring. The mixing was done with great care to ensure uniform mixing and to prevent segregation. The use of high-purity copper ensures minimal interference from impurities, thus allowing for a more accurate assessment of its effects on the microstructure and mechanical properties of the material, particularly on the ability of the material to form pearlite in cast iron. Similarly,

the duration of the shake-out was varied to examine the effect on the cooling rate, residual stress, and microstructural development. These parameters are selected assuming that they represent the main parameters of the process that are most likely to affect the mechanical properties of the CI200 grade cast iron, while keeping the other parameters of the process constant. This assumption is widely recognized in experimental casting studies to explain the experimental results of the primary effects of specified control variables.

Table 2. Level of experiment

Parameters	Level 1	Level 2	Level 3
Magnetic Intensity in Gauss	0	3000	6000
Shake out time in Seconds	3600	5400	7200
Cu Percentage in Percentage	0.5	1	1.5

3.2. Experimental Design Matrix

The experimental matrix was designed using the Taguchi L9 orthogonal array, in which nine experimental trials were performed with different combinations of process parameters. All experiments were performed under regulated conditions, and the design matrix is displayed in Table 3. To enhance reliability and minimize experimental error, each trial was conducted thrice, and the mean values were utilized for subsequent analysis.

Table 3. Taguchi orthogonal array design matrix

Sample	Magnetic field intensity in Gauss	Shake out time in seconds	Copper Percentage
Sample 1	0	3600	0.5
Sample 2	0	5400	1
Sample 3	0	7200	1.5
Sample 4	3000	3600	1
Sample 5	3000	5400	1.5
Sample 6	3000	7200	0.5
Sample 7	6000	3600	1.5
Sample 8	6000	5400	0.5
Sample 9	6000	7200	1

3.3. Assumption in Experimental Design

To be sure the experiment would work and to make the complicated casting process easier, the following assumptions were made: Due to the way the permanent magnets are arranged, a steady magnetic field is created in the mold cavity. During pouring, the flow of molten metal is steady and controlled, which reduces turbulence. To see how the specified parameters affect the process, other aspects, such as the material of the mold, the temperature of the pouring, and the composition, are kept the same. These assumptions are logical and commonly utilized in similar experimental

research, as they enable focused analysis of main influencing elements without significantly undermining the validity of the findings.

3.4. Experimental Setup and Magnetic Field Application

Figure 1 shows a schematic drawing of the experimental setup using a permanent magnet. Symmetrically stacking permanent magnets around the mold cavity was done to obtain a stable and uniform magnetic field. This design provides a uniform flow of the molten metal, and thus, it is useful to improve the ability to fill the mold and control the solidification rate. The separation between the magnet assembly and mold center was maintained at approximately 20 cm while the casting position was maintained at 25 mm from the reference center. The alignment, orientation, and spacing of the magnets were kept constant throughout all the trials to avoid any variation in the magnetic field distribution. To make sure the experiments were conducted correctly and in the same manner, the magnetic field intensity was measured at the middle of the mold cavity before each experiment using a calibrated Gauss meter.

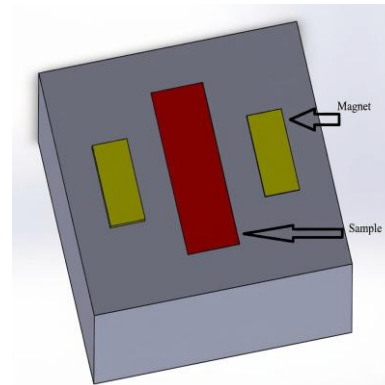


Fig. 1 Magnetic field casting diagram

Figure 2 shows the arrangement of the stacked permanent magnets with north and south poles set. The magnetic fields are stable and have an influence on the flow of molten metal and the microstructural changes during solidification. The magnetic field was generated with Neodymium permanent magnets, which have superior magnetic and stability properties. The cross-section of each magnet was 2cm x 2cm, and its length was 8cm. Four magnets were symmetrically set around the mold cavity for a magnetic field strength of 6000 gauss. The two magnets were used in a similar arrangement for 3000 gauss. At 0 gauss, no magnetic field was applied.

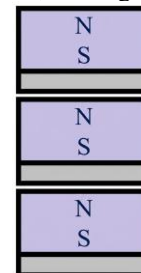


Fig. 2 Positioned of permanent magnet stacked in the casting mold

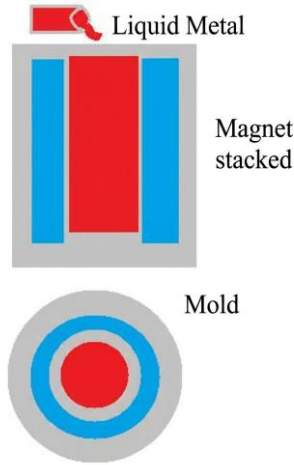


Fig. 3 Schematic view showing molten metal flow into a mould in the presence of a permanent magnet

3.5. Casting Procedure

The CI200 grade cast iron was melted at about 1350 °C and poured into the mould at about 1200 °C to ensure good fluidity and prevent premature solidification. The casting samples were all made in a CO₂ sand mould. The mould has been manufactured by a standard industrial mold-making process to ensure uniformity in quality. Silica sand used was about 90-92%, sodium silicate binder about 6-8%, and uniform CO₂ gas hardening was applied. The mould chamber was designed to make specimens 30 cm long and 24 mm in rectangular cross-section. The mould hardness was maintained in a normal range of 70 to 80 (mould hardness number) to ensure that it had enough strength and permeability property. The copper powder was added to the molten metal in certain proportions, prior to pouring, to ensure uniformity.

The agitation was done thoroughly to achieve uniform dispersion of copper in the molten material. All casting circumstances were meticulously regulated and kept constant during the testing. Figure 3 shows a schematic of the molten metal flow under a magnetic field, and how this affects the flow uniformity and characteristics of solidification. Each trial run was repeated 3 times to ensure the same and correct. The average responses of the responses assessed were used for the analysis. Calibrated instruments were used to minimize measurement uncertainties, and standardized operating procedures were used to minimize external deviations. Therefore, it is assumed that the main reason for the changes in mechanical properties has to do with the process parameters that were selected, which in this case include the strength of the magnetic field, the quantity of copper being added, and the duration of the shake-out. This confirms the choice of experimental design and model. Possible elements that could affect the results, like changes in the temperature of the environment, differences in the materials, and measurement errors, were reduced by using calibrated instruments and setting up controlled operating settings. The observed differences in mechanical properties are mainly due to the strength of the magnetic field, the copper content, and the shaking time.

4. Experimental Methodology

4.1. Microstructure Analysis

Microstructural analysis shows that the phase distribution in CI200 cast iron is directly and closely related to the processing parameters. The results of the investigation show that the addition of copper and application of a magnetic field significantly influence the phase distribution and phase shape.

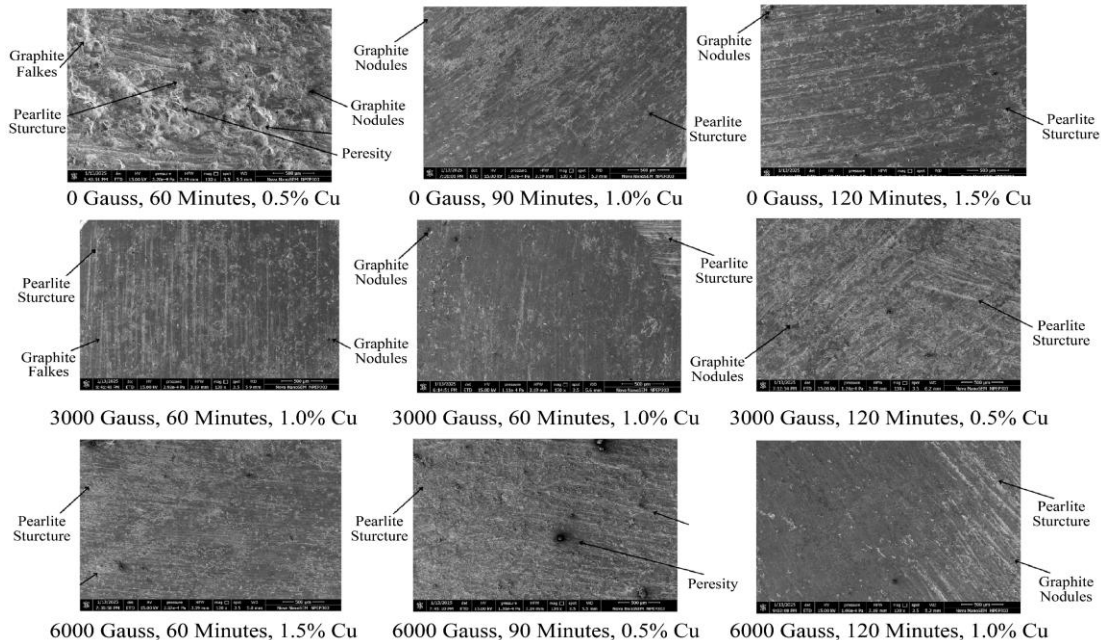


Fig. 4 Microstructure morphology of CI200 with changing process parameters

The microstructures of the samples of CI200 grade cast iron are shown in Figure 4, in which small Fe₃C (cementite) peaks were found, especially in the sample containing the high copper concentration, where the formation of carbide has been attributed to the presence of copper, which makes the cementite phase more stable. This study indicates that the inclusion of copper not only alters the matrix structure but also refines carbide production, resulting in enhanced hardness properties. The graphite structural distribution in CI200 grade cast iron material, subjected to a 6000 gauss magnetic field for 7200 seconds, achieved a homogeneous arrangement of graphite flakes exhibiting Type A morphology. This demonstrates steady solidification conditions and enhances microstructural homogeneity. Furthermore, the addition of 1% weight copper facilitated the refinement of the pearlite structure.

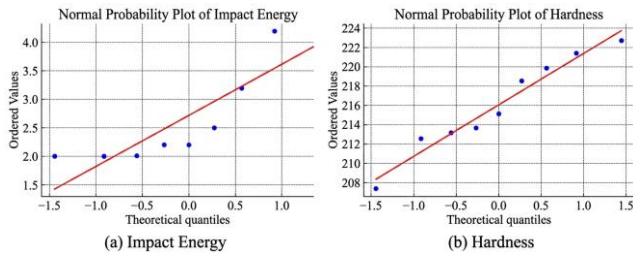


Fig. 5 The normal probability plot, a) Impact energy, b) Hardness property.

The normal probability plots for mechanical properties such as hardness and impact energy indicate that the experimental data closely adhere to a linear trend, hence validating the normal distribution of the data. This confirms the appropriateness of utilizing parametric statistical methods, including investigation of variance and regression modeling, for subsequent investigation.

Table 4. Analysis of Variance (ANOVA)

Source	Mean Square	F-Value	P-Value	Significance
Magnetic Field	2.16	12.5	0.006	Significant
Shake-Out Time	1.09	6.3	0.032	Significant
Copper	0.53	3.1	0.112	Not Significant
Error	0.17	-	-	-

Table 4: Conduct an Analysis of Variance (ANOVA) to examine the effects of magnetic field intensity, shake-out time, and the inclusion of copper alloying elements on casting parameters. Analysis of Variance (ANOVA) was used to determine the significance of the selected process parameters from the experimental data. The results show that the intensity of the magnetic field has the strongest effect with an F-value of 12.5 and a P-value of 0.006, confirming its strong statistical significance. The duration of shake-out has a significant effect

on the response variables as per the F value of 6.3 and P value of 0.032, which clearly indicates the importance of controlling the mechanical properties. However, the effect of the addition of copper is less pronounced, as shown by a higher P-value (0.112), suggesting that copper has a less significant effect in the range of values studied. The ANOVA results show that magnetic field intensity is a statistically significant parameter on the strength of the material.

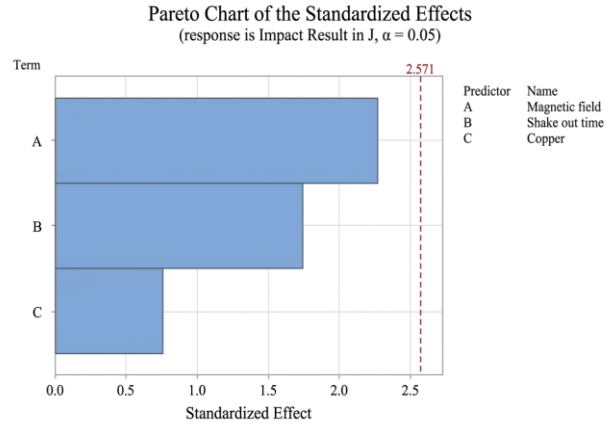


Fig. 6 Pareto chart of the standardized effect on casting at different process parameters

Figure 6 shows the Pareto Chart of the effects of different parameters on the response variables in the casting process in standardized terms. The graphic shows the relative influence of the components of the process parameters, and the interactions between them, in order of their relative standardized effects. When examining the thresholds, the factors magnetic field intensity and its interaction term clearly show their effect on the response. Parameters whose bars are not within the line are considered to be statistically significant and thus have an effect on the model performance and output. In this study, the result of ANOVA was confirmed, and it highlights the importance of magnetic field intensity as the most critical parameter for the response parameters.

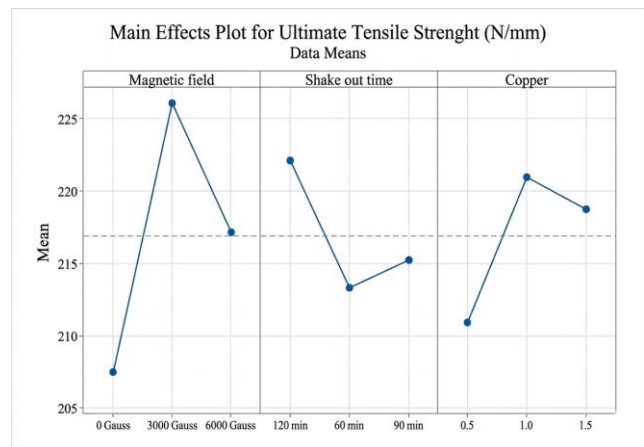


Fig. 7 Main effect plot for tensile strength

As shown in Figure 7, the magnetic field, shake-out duration, and copper concentration have significant effects on the final Tensile Strength (UTS) of CI200 grade cast iron. The magnetic field had the greatest influence with a maximum Ultimate Tensile Strength (UTS) at 3000 Gauss, and a slight drop in strength at 6000 Gauss. The 7200-second shake-out duration yielded the best ultimate tensile strength owing to enhanced cooling and stress relaxation. The incorporation of copper enhanced the Ultimate Tensile Strength (UTS), with 1.0% Cu being the optimal outcome, whereas increased copper concentrations resulted in a marginal decline.

4.2. Mechanical Properties

The mechanical properties were assessed in accordance with established standard testing protocols. The mechanical properties of CI200 grade cast iron material were evaluated in accordance with the ASTM A857 standard specification. Table 5 presents the mechanical parameters of CI200 utilized in this research, derived from experimental results.

Table 5. Mechanical property of CI200

Sample	Tensile Strength in MPa	Hardness in BHN	Impact Toughness in J
Sample 1	197.86	207.43	2.01
Sample 2	210.13	219.8	2
Sample 3	214.54	215.13	2
Sample 4	226.49	213.2	2.2
Sample 5	226.04	212.56	2.2
Sample 6	225.49	222.7	4.2
Sample 7	215.71	213.66	3.2
Sample 8	209.48	221.4	2.5
Sample 9	226.21	218.5	4.2

The mechanical properties of CI200 grade cast iron material were evaluated using tensile strength, impact testing, and hardness testing. The strength has improved, although sample 1 has the lowest tensile strength at 197.86 MPa without a magnetic field. Samples 4 and 9 have the highest values at 225.49 MPa and 226.21 MPa, respectively, when the magnetic field is over 3000 gauss.

The impact toughness data show that samples 6 and 9 got better, with a peak value of 4.2 J at 3000 Gauss and 6000 Gauss, and a shake-out time of 7200 seconds. The baseline process (0 Gauss) had the lowest values, which means that increasing the strength of the magnetic field makes energy absorption better.

The hardness value shows that the material behaves in a stable way. The highest hardness was observed at sample 6 (222.7 BHN), where the magnetic intensity was 3000 gauss and the shake-out time was 7200 seconds. The higher copper concentration makes CI200 grade cast iron harder because the transition of pearlite has a strong stabilizing effect. The results show that the process settings used improved the mechanical

properties of the CI200 material. Upon reviewing prior research papers and experimental findings, it was noted that tensile strength improved by 10 to 40%, hardness rose by 10 to 30%, and impact energy exhibited a minor improvement.

Table 6. Comparative analysis of the mechanical property of CI200

Process	Tensile Strength in MPa	Hardness in BHN
Conventional Method	200	180
Magnetism Method	226.41	221.4

The experimental results from this work indicate a significant enhancement in the mechanical properties of CI200 grade cast iron compared to widely documented values in the literature. Previous Literature studies show that regular CI200 grade cast iron has a tensile strength maximum of about 200 MPa and a hardness of about 180 BHN when cast in a normal way. On the other hand, this study reached a maximum tensile strength of 226.41 MPa and a hardness of 221.4 BHN under optimized conditions, such as when a magnetic field was used, and copper was added.

A study on copper alloying in cast iron shows that copper promotes pearlite formation and makes the metal harder, but its effects are limited when used alone. Studies on magnetic field-assisted casting demonstrate that magnetic fields enhance the flow of molten metal and refine microstructure; nevertheless, current investigations primarily focus on non-ferrous alloys or neglect the effects of combinatorial factors. The improvements may be traced back to better microstructure and more pearlite production, which is due to the combined effects of changing the process and adding alloying.

This study demonstrates that their synergistic use yields a more substantial enhancement in strength and hardness. The impact strength showed very little change, which suggests that the changes mostly affect strength-related factors and not toughness. The results show that using magnetic fields and copper together is a better way to improve the performance of CI200 grade cast iron than using standard methods.

This confirms that the combined effects of magnetic field strength, shake-out time, and copper addition improve performance compared to traditional casting or changing one parameter at a time. This study not only confirms previous findings but also improves them by showing a more effective and useful way to improve the properties of CI200 grade cast iron.

4.3. Process Optimization

In this experiment, numerous parameters were employed that differed in accordance with prior research. To determine an examination set of process parameters based on the optimal material attributes at those parameters. Optimal performance of the procedure is necessary.

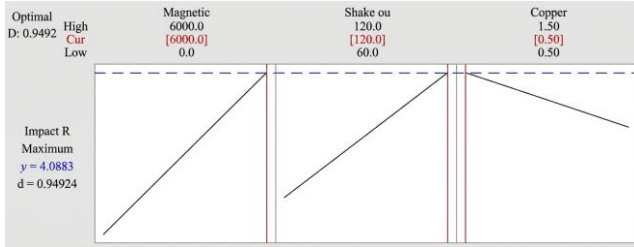


Fig. 8 Process parameter with response variable for impact energy

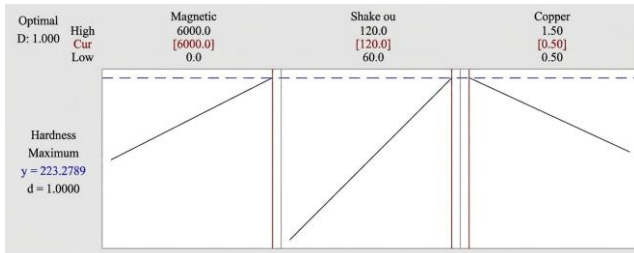


Fig. 9 Process parameter with response variable for hardness

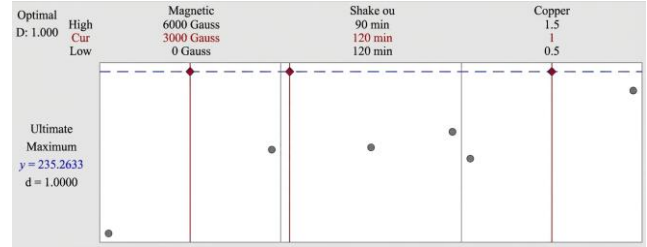


Fig. 10 Process parameter with response variable for tensile strength

Response optimization and composite desirability analysis were conducted via the Minitab response optimizer. Response optimization was attained with a composite desirability of 0.9.

The model forecasts maximum impact energy of 4.2 J when subjected to the highest magnetic field and shake-out duration of 7200 seconds, alongside a minimal copper concentration of 0.5 weight %

Table 7. Optimization of process parameter results

Process Parameter	Optimal level for combined performance	Microstructure effect	Primary Mechanical Outcomes
Magnetic field	6000 Gauss	Refine graphite, homogenize the matrix	Maximum Impact Toughness (4.2 J), strength (226.21 MPa)
Shake-Out Time	7200 seconds	Enable complete pearlitic Transformation	Enhance Toughness, Hardness
Copper Addition	1.0 weight %	Stabilize fine, uniform pearlite matrix	Optimize impact, tensile strength
Overall Result	6000 Gauss, 7200 seconds, 1.0 weight % Cu	Uniform Microstructure, Type A, Fine Graphite Pearlite matrix	Enhance Mechanical Property

Consequently, Table 7 indicates that the best conditions (6000 Gauss, 7200 seconds, and 1.0% copper) yield a balanced combination of process parameters that enhance material refinement uniformity. The toughness is improved by a refined, homogeneous graphite distribution and a uniform matrix, while hardness is sustained by fine and complete structures.

4.4. Discussion on Combined Effect and Mechanism of Properties Improvement

The enhanced performance in ideal conditions is due to the synergistic interplay of process factors. The synergistic interaction between the process parameters is responsible for the improved performance in optimal conditions. The magnetic field facilitates flow and solidification of the molten metal, and the shake-out time determines the cooling rate and the distribution of stress. Copper promotes the growth of pearlite phase and stabilizes the matrix. The consistent application of this leads to a consistent microstructure, reduced casting defects, and improved mechanical properties. If a magnetic field is generated during the solidification process, it alters the flow of molten metal and enhances heat

distribution and cooling. This decreases the turbulence and minimizes the casting defects, including porosity and micro-shrinkage. This leads to an even microstructure. The shape of the flakes of graphite was observed to have changed. The graphite flakes in regular cast iron are typically irregular and fragmented, leading to areas of stress concentration and reducing the strength of the metal. In the presence of the magnetic field, the graphite flakes were spread out evenly and continuously (Type A morphology). Although the flakes appeared larger, they were more uniform in alignment and less broken up, thereby minimizing stress concentration and load transfer within the matrix. In contrast, in conventional casting, the graphite flakes are usually broken and dispersed unevenly, making the structure weak.

Copper stabilizes the pearlite, allowing it to be distributed uniformly and creating a more refined gap between the pearlite layers. This increases the strength of the material. Fewer defects, improved graphite formation, and stronger pearlite structure result in better mechanical properties. More continuous graphite flakes make the material tougher, and the strengthened matrix makes the material stronger and harder.

The observed improvement is not due to one thing, but rather to the combined effects of magnetic field-induced solidification regulation and copper-induced matrix fortification. This study shows that there are more continuous and evenly distributed flakes in this Type of cast iron, which improves its mechanical performance. In typical cast iron, discontinuous graphite flakes are where cracks start.

4.5. Industrial Relevance

This work demonstrates a practical and industry-relevant approach to improving the mechanical properties of CI200 grade cast iron through the concurrent application of a magnetic field, shake-out period, and copper incorporation. Permanent magnets offer a simple, cheap, and energy-efficient alternative to complex electromagnetic systems. They can be easily added to existing foundry operations without any changes to the equipment. The magnetic field setup used in this work, which consists of permanent magnets attached to the outside, can be easily added to classic sand casting methods. This renders the way very appropriate for small and medium-sized foundries where cost and ease of use are very significant.

The improvement in tensile strength (up to approximately 226 MPa) and hardness (up to approximately 221 BHN) indicates that the new process is suitable for manufacturing parts that are able to withstand loads and wear, including engine components for vehicles (such as cylinder blocks and brake drums), pump housings and impellers, machine tool bases, motor casings, and gear housings. This improves the reliability and durability of the product due to reduced casting faults and enhanced consistency of microstructure. Using permanent magnets in industry eliminates the need for continual power use, making the process environmentally friendly and energy-efficient. The method is scalable since you can change the strength of the magnetic field by changing the number and arrangement of the magnets. So, the recommended method is a practical, scalable, and cost-effective way to improve the quality of cast iron, making it very suitable for real-world industrial uses. The established technology may be easily added to existing casting methods with only a few changes, making it possible to use it in industry.

5. Conclusion

This study investigated the combined effects of magnetic field intensity, copper incorporation, and shake-out time on the mechanical properties of CI200 grade cast iron. The experimental results indicate that the selected parameters significantly influence mechanical qualities, including tensile strength and hardness, while exerting minimal effect on

toughness. The maximum tensile strength was 226.49 MPa, and the hardness was 222.7 BHN. Both of these values are approximately 13.25% and 11.35% higher than normal CI200 grade cast iron values. The properties are improved by changes to the microstructure that occur during solidification. The addition of a magnetic field also increased the nucleation density, and the Type A graphite flakes were distributed more evenly. Copper was used as a pearlite stabilizer, making the matrix stronger, and the appropriate amount of shake-out time was used to make the structure even and homogeneous. These effects resulted in an optimized microstructure and the overall performance of the material.

The factor of magnetic field intensity was found to be the most important factor, followed by the duration of the shake-out, while the addition of copper has a negligible effect within the range of this study, as concluded from the ANOVA statistical analysis. Taguchi optimization also revealed that the optimum set of parameters for best mechanical performance was 6000 gauss magnetic field strength, shake-out time of 7200 seconds, and copper addition of 1.0 wt.%.

This study is the first to examine these aspects together and demonstrates that the combination of all of them results in a greater improvement in the mechanical properties. This work describes an effective casting method for improving the properties of CI200 cast iron and gives valuable insights into the correlation between the casting process, the structure, and characteristics of the castings for industrial applications. This experimental study suggests that further research should be conducted, such as the use of different grades as per industry specifications and the study of the effects of different orientations, positions, and intensities of the magnetic field on cast iron.

Conflicts of Interest

The authors have no conflicts of interest to declare with regard to the publication of this paper.

Funding Statement

The authors have not been supported financially for the research, experimental finance, authorship, or publication of this article.

Acknowledgments

The Author thanks the Pravara Rural Engineering College, affiliated with Savitribai Phule Pune University, and Star Casting Pvt. Ltd., MIDC Ahilyanagar, for support and the lab facility provided for magnetic field-assisted casting experimentation.

References

- [1] J. O. Agunsoye et al., "The Effect of Copper Addition on the Mechanical and Wear Properties of Grey Cast Iron," *Journal of Minerals and Materials Characterization and Engineering*, vol. 2, no. 5, pp. 470-483, 2014. [[CrossRef](#)] [[Google Scholar](#)] [[Publisher Link](#)]

- [2] Samar Reda Al-Sayed, Haytham Elgazzar, and Adel Nofal, "A Comparative Study of Laser Fluence Effect on Surface Modification and Hardness Profile of Austempered Ductile Iron," *Journal of Materials Research and Technology*, vol. 31, pp. 3189-3204, 2024. [[CrossRef](#)] [[Google Scholar](#)] [[Publisher Link](#)]
- [3] P. Atanda, G. Oluwadare, and O. Oluwole, "Effect of Silicon Content and Shake-Out Time on Hardness and Grain Size Properties of GL 250 Cast Iron," *Journal of Minerals and Materials Characterization and Engineering*, vol. 10, no. 3, pp. 257-266, 2011. [[CrossRef](#)] [[Google Scholar](#)] [[Publisher Link](#)]
- [4] Fengmin Du et al., "Investigation on Non-Uniform Friction Behaviors of Slab during Continuous Casting based on an Inverse Algorithm," *Journal of Materials Processing Technology*, vol. 288, pp. 116-129, 2021. [[CrossRef](#)] [[Google Scholar](#)] [[Publisher Link](#)]
- [5] Ruziye Camkerten et al., "The Relationships among Microstructure, Impact Toughness and Wear Resistance in Newly Developed Austempered Low Alloy White Cast Iron," *Journal of Alloys and Compounds*, vol. 10, 2025. [[CrossRef](#)] [[Google Scholar](#)] [[Publisher Link](#)]
- [6] Li Xinxu et al., "Segregation and Homogenization for a New Nickel-Based Superalloy," *Vacuum*, vol. 177, 2020. [[CrossRef](#)] [[Google Scholar](#)] [[Publisher Link](#)]
- [7] B. Podgornik et al., "Microstructure Refinement and its Effect on Properties of Spring Steel," *Materials Science and Engineering A*, vol. 599, pp. 81-86, 2014. [[CrossRef](#)] [[Google Scholar](#)] [[Publisher Link](#)]
- [8] Amar Sabih, Priti Wanjara, and James Nemes, "Characterization of Internal Voids and Cracks in Cold Heading of Dual Phase Steel," *ISIJ International*, vol. 45, no. 8, pp. 1179-1186, 2005. [[CrossRef](#)] [[Google Scholar](#)] [[Publisher Link](#)]
- [9] Shenqiang Wang et al., "Magnetohydrodynamic Phenomena, Fluid Control and Computational Modeling in the Continuous Casting of Billet and Bloom," *ISIJ International*, vol. 54, no. 10, pp. 2273-2282, 2014. [[CrossRef](#)] [[Google Scholar](#)] [[Publisher Link](#)]
- [10] Shaoxiang Li et al., "Analysis on Electromagnetic Field of Continuous Casting Mold Including a New Integral Method for Calculating Electromagnetic Torque," *Metals*, vol. 9, no. 9, pp. 1-15, 2019. [[CrossRef](#)] [[Google Scholar](#)] [[Publisher Link](#)]
- [11] Agung Setyo Darmawan et al., "Engineering Hardness and Toughness of Gray Cast Iron with the Addition of Silicon Elements," *Journal of Physics: Conference Series*, vol. 2972, pp. 1-9, 2025. [[CrossRef](#)] [[Google Scholar](#)] [[Publisher Link](#)]
- [12] Yishuo He et al., "The Influence of Trace Vanadium on the Solidification Process, Microstructure, and Mechanical Properties of Gray Cast Iron," *Journal of Materials Research and Technology*, vol. 31, pp. 998-1007, 2024. [[CrossRef](#)] [[Google Scholar](#)] [[Publisher Link](#)]
- [13] Bolarinwa Johnson Kutelu, Raymond Taiwo Oluyori, and Dada Oluwadare Omoyeni, "Microstructure Characteristics and Mechanical Properties of Grey Cast Iron at Varied Ferrosilicon Addition," *ABUAD Journal of Engineering Research and Development*, vol. 7, no. 2, pp. 290-296, 2024. [[CrossRef](#)] [[Google Scholar](#)] [[Publisher Link](#)]
- [14] Katarzyna Makowska, and Zbigniew L. Kowalewski, "Analysis of the Microstructure and Hardness of Flake Graphite Cast Iron using the Barkhausen Noise Method and Conventional Techniques," *Journal of Nondestructive Evaluation*, vol. 43, pp. 1-12, 2024. [[CrossRef](#)] [[Google Scholar](#)] [[Publisher Link](#)]
- [15] Mohamed Mourad, Mervat Ibrahim, and Shima El-Hadad, "Effect of Copper Addition on Microstructure and Mechanical Properties of Ductile Cast Iron," *International Journal of Materials Technology and Innovation*, vol. 4, no. 1, pp. 75-79, 2024. [[CrossRef](#)] [[Google Scholar](#)] [[Publisher Link](#)]
- [16] Saliu Ojo Seidu, Daniel Toyin Oloruntoba, and Iyiola Olatunji Otunniyi, "Effect of Shakeout Time on Microstructure and Hardness Properties of Grey Cast Iron," *Journal of Minerals and Materials Characterization and Engineering*, vol. 2, no. 4, pp. 346-350, 2014. [[CrossRef](#)] [[Google Scholar](#)] [[Publisher Link](#)]
- [17] N.V. Stepanova, A.A. Razumakov, and E.A. Lozhkina, "Structure and Mechanical Properties of Cu-Alloyed Cast Iron," *Applied Mechanics and Materials*, vol. 682, pp. 178-182, 2014. [[CrossRef](#)] [[Google Scholar](#)] [[Publisher Link](#)]
- [18] Saranya Panneerselvam et al., "Influence of Intercritical Austempering on the Microstructure and Mechanical Properties of Austempered Ductile Cast Iron (ADI)," *Materials Science and Engineering A*, vol. 694, pp. 72-80, 2017. [[CrossRef](#)] [[Google Scholar](#)] [[Publisher Link](#)]
- [19] Farjad Alabbasian, Seyyed Mohammad Ali Boutorabi, and Shahram Kheirandish, "Effect of Inoculation and Casting Modulus on the Microstructure and Mechanical Properties of Ductile Ni-Resist Cast Iron," *Materials Science and Engineering A*, vol. 651, pp. 467-473, 2016. [[CrossRef](#)] [[Google Scholar](#)] [[Publisher Link](#)]
- [20] André de Albuquerque Vicente et al., "Nucleation and Growth of Graphite Particles in Ductile Cast Iron," *Journal of Alloys and Compounds*, vol. 775, pp. 1230-1234, 2019. [[CrossRef](#)] [[Google Scholar](#)] [[Publisher Link](#)]
- [21] Yangzhen Liu et al., "Effect of Graphite Morphology on the Tensile Strength and Thermal Conductivity of Cast Iron," *Materials Characterization*, vol. 144, pp. 155-165, 2018. [[CrossRef](#)] [[Google Scholar](#)] [[Publisher Link](#)]