

Research and Development Project in BITAC titled as-

“Development of Nodular Cast Iron using Indigenous Raw Materials and Technology”

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Introduction

Nodular Cast Iron Definition: Nodular cast iron, also known as ductile iron or spheroidal graphite iron, is a type of cast iron that possesses unique properties due to the presence of graphite nodules or spheroids within its microstructure. Unlike traditional cast iron, which contains flake graphite, nodular cast iron has a matrix of ferrite and pearlite surrounding the graphite nodules.

The graphite nodules in nodular cast iron are formed during the manufacturing process by adding specific nodulizing agents, typically magnesium or cerium, to the molten iron. These agents help promote the formation of graphite in a spheroidal or nodular form rather than the flake form found in conventional cast iron. This process imparts several advantageous properties to nodular cast iron, including high tensile strength, excellent impact resistance, good wear resistance, and high thermal conductivity.

The nodules in nodular cast iron act as "crack arresters" by preventing the propagation of cracks and distributing stress throughout the material. This enhances its toughness and ductility, allowing it to withstand heavy loads and absorb shock without fracturing. As a result, nodular cast iron combines the strength and stiffness of cast iron with the ductility and impact resistance of steel.

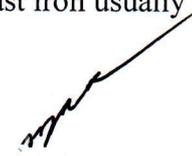
The manufacturing process for nodular cast iron involves melting scrap iron or iron ore in a furnace and adding the nodulizing agents at a controlled temperature. The molten metal is then poured into molds to form the desired shape and allowed to cool and solidify. The cooling process allows the graphite nodules to form within the matrix of ferrite and pearlite, giving nodular cast iron its distinctive microstructure.

In summary, nodular cast iron is a type of cast iron that exhibits superior mechanical properties due to the presence of graphite nodules. Its strength, ductility, and wear resistance make it a highly sought-after material for a wide range of applications, particularly in industries where durability and performance are essential.

Chemical Composition of Nodular Cast Iron: The chemical composition of nodular cast iron, also known as ductile iron or spheroidal graphite iron, typically consists of the following elements:

1. Iron (Fe): Iron is the primary component of nodular cast iron, typically constituting around 92-94% of the material's composition. It provides the base metal for the alloy.
2. Carbon (C): Carbon is an essential element in cast iron, including nodular cast iron. It contributes to the material's strength and hardness. The carbon content in nodular cast iron typically ranges from 3.2% to 4.0%.
3. Silicon (Si): Silicon is commonly added to nodular cast iron as a deoxidizing agent during the manufacturing process. It improves the fluidity of the molten metal and enhances castability. The silicon content in nodular cast iron usually ranges from 1.8% to 2.8%.


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4. **Manganese (Mn):** Manganese is added to nodular cast iron to improve its mechanical properties, such as strength and hardness. It also helps in the formation of graphite nodules. The manganese content in nodular cast iron typically ranges from 0.1% to 0.5%.
5. **Magnesium (Mg):** The magnesium content in nodular cast iron typically ranges from 0.03% to 0.1%. This relatively small amount of magnesium is sufficient to facilitate the formation of graphite nodules, ensuring the material's enhanced mechanical properties.
6. **Sulphur (S):** Sulphur is considered an undesirable element in nodular cast iron as it can impair the material's ductility and toughness. Therefore, the sulphur content is usually kept low, typically below 0.05%.
7. **Phosphorus (P):** Phosphorus is another element that is typically kept low in nodular cast iron, as higher levels can negatively impact the material's ductility and toughness. The phosphorus content is generally limited to a maximum of 0.1%.
8. **Traces of Other Elements:** Nodular cast iron may also contain trace amounts of other elements, such as copper (Cu), nickel (Ni), chromium (Cr), and molybdenum (Mo). These elements are often present in small quantities and can contribute to specific properties or characteristics required for specific applications.

It is important to note that the exact chemical composition of nodular cast iron can vary depending on the specific grade, intended application, and manufacturing process. Different grades of nodular cast iron may have slightly different compositions to meet specific performance requirements. The below Table 1 provides standard composition range of Nodular Cast Iron-

Element	Fe	C	Si	Mn	Mg	S	P
Percentage (%)	92-94	3.2-4.0	1.8-2.8	0.1-0.5	0.03-0.1	<0.05	<0.1

Table 1: Standard chemical composition of Nodular Cast Iron

The chemical composition of nodular cast iron is carefully controlled during the manufacturing process to achieve the desired mechanical properties, including high strength, excellent ductility, and good wear resistance.

Microstructure of Nodular Cast Iron: The microstructure of nodular cast iron, also known as ductile iron or spheroidal graphite iron, is characterized by the presence of graphite nodules or spheroids within a matrix of ferrite and pearlite. This unique microstructure distinguishes nodular cast iron from other types of cast iron, such as gray iron, which contains flake graphite.

The formation of graphite nodules is achieved through the addition of nodulizing agents, typically magnesium or cerium, during the manufacturing process. These agents promote the nucleation and growth of graphite in a spheroidal or nodular form. The presence of graphite nodules contributes


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to the material's exceptional mechanical properties, including high strength, excellent ductility, and good impact resistance.

The matrix of nodular cast iron consists primarily of ferrite and pearlite phases. Ferrite is a relatively soft and ductile phase composed of pure iron. It provides the matrix with toughness and ductility, contributing to the overall mechanical behavior of nodular cast iron. Pearlite, on the other hand, is a eutectoid mixture of ferrite and cementite. It is harder and stronger than ferrite and provides nodular cast iron with additional strength.

The distribution, shape, and size of the graphite nodules within the matrix play a crucial role in determining the mechanical properties of nodular cast iron. The graphite nodules act as "crack arresters" by impeding the propagation of cracks and distributing stress throughout the material. This enhances the toughness and impact resistance of nodular cast iron, allowing it to withstand heavy loads and absorb energy without fracturing.

The microstructure of nodular cast iron can be examined using metallographic techniques such as optical microscopy, scanning electron microscopy (SEM), or transmission electron microscopy (TEM). These techniques allow for the visualization and analysis of the graphite nodules, ferrite, pearlite, and any other phases or inclusions present in the material.

In summary, the microstructure of nodular cast iron consists of graphite nodules dispersed within a matrix of ferrite and pearlite. This unique microstructure, facilitated by the addition of nodulizing agents, contributes to the material's exceptional mechanical properties, making it a versatile and reliable choice for various industrial applications. The below figures provide some standard microstructure of Nodular Cast Iron-

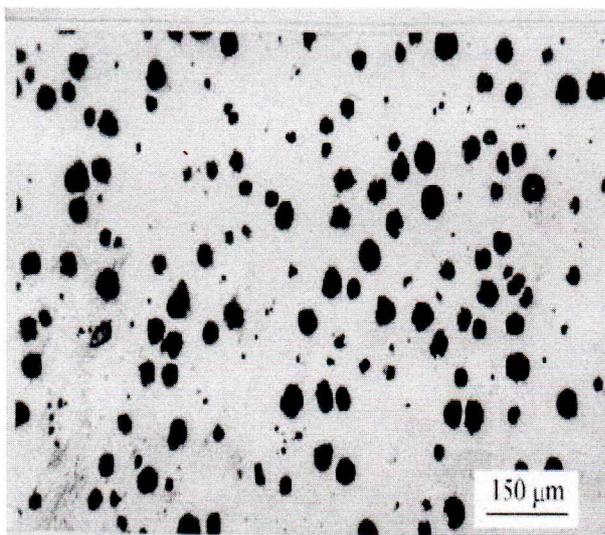


Figure 1: Standard Nodular Cast Iron Before Etching

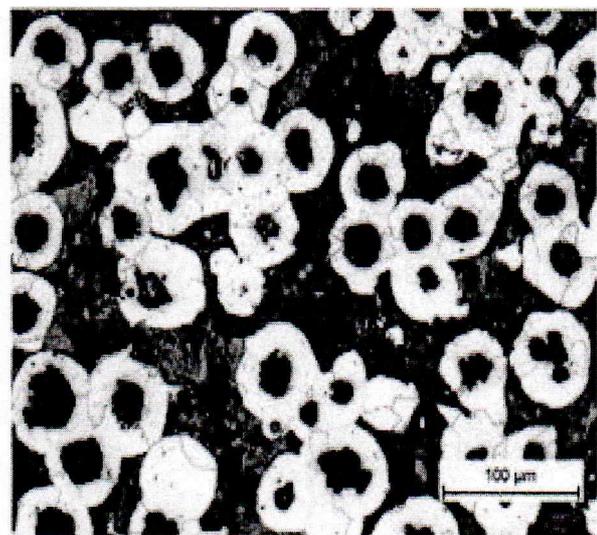


Figure 2: Standard Nodular Cast Iron After Etching


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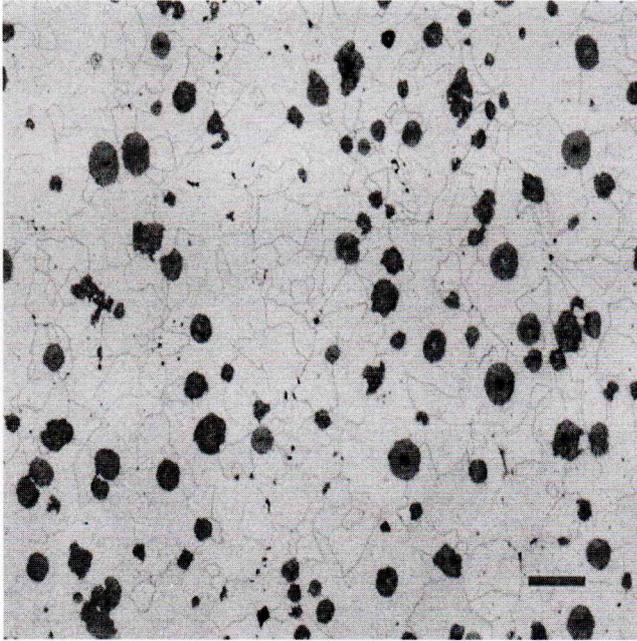


Figure 3: Ferritic Nodular Cast Iron Before Etching

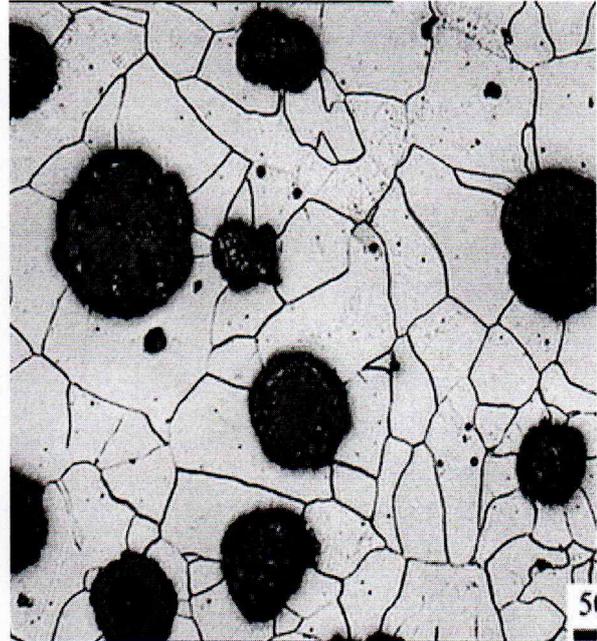


Figure 4: Ferritic Nodular Cast Iron After Etching

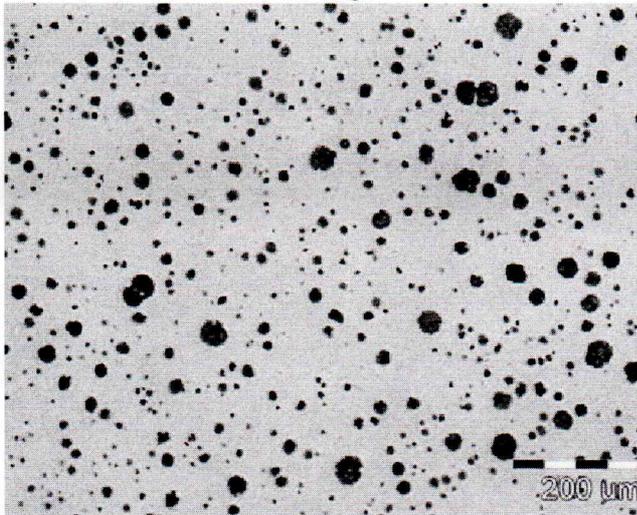


Figure 5: Pearlitic Nodular Cast Iron Before Etching

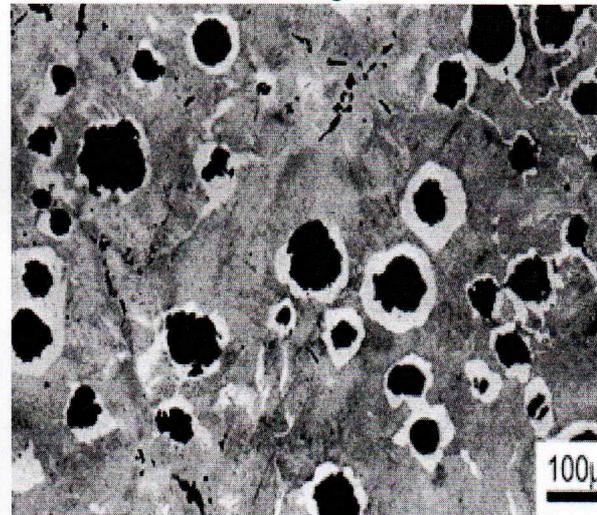
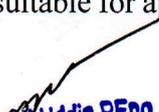


Figure 6: Pearlitic Nodular Cast Iron After Etching

Properties of Nodular Cast Iron: Nodular cast iron, also known as ductile iron or spheroidal graphite iron, possesses several advantageous properties that make it a highly sought-after material in various industries. Here are some key properties of nodular cast iron:

1. **High Strength:** Nodular cast iron exhibits high tensile strength, providing it with excellent structural integrity and load-bearing capacity. Its strength is comparable to that of many low to medium carbon steels, making it suitable for applications where strength is a critical requirement.


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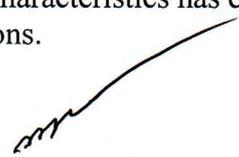

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2. **Good Ductility:** Unlike traditional gray cast iron, which is brittle, nodular cast iron has good ductility. This property allows it to undergo plastic deformation without fracturing, making it more resistant to cracking and offering greater flexibility in design and manufacturing.
3. **Exceptional Impact Resistance:** Nodular cast iron has excellent impact resistance, which is attributable to the presence of graphite nodules within its microstructure. These nodules act as "crack arresters," absorbing and dissipating energy when subjected to sudden impacts, thereby preventing the propagation of cracks and increasing the material's toughness.
4. **Excellent Wear Resistance:** Nodular cast iron is highly resistant to wear and abrasion. The presence of graphite nodules helps to provide a self-lubricating effect, reducing friction and minimizing surface damage, making it ideal for applications that involve sliding or abrasive wear, such as gears, pistons, and cylinder liners.
5. **Corrosion Resistance:** Nodular cast iron exhibits good corrosion resistance, particularly in environments where moisture, chemicals, or acidic conditions are present. However, its corrosion resistance can be enhanced further through protective coatings or surface treatments.
6. **Thermal Conductivity:** Nodular cast iron has high thermal conductivity, allowing for efficient heat transfer. This property makes it suitable for applications where heat dissipation or thermal management is essential, such as engine components or heat exchangers.
7. **Machinability:** Nodular cast iron is relatively easy to machine compared to other materials like steel. It has good cutting characteristics, enabling the production of intricate shapes and precise components. This property facilitates cost-effective manufacturing processes.
8. **Damping Properties:** Nodular cast iron has excellent damping properties, which means it can absorb and dissipate vibrations and noise. This makes it ideal for applications where noise reduction and vibration damping are crucial, such as engine blocks or machinery components.
9. **Cost-Effective:** Nodular cast iron offers a cost-effective alternative to materials like steel, while still providing comparable or even superior performance. Its availability and relatively low production costs make it an attractive choice for many applications.

These properties make nodular cast iron a versatile material used in a wide range of industries, including automotive, machinery, construction, and more. Its unique combination of strength, ductility, wear resistance, and other beneficial characteristics has contributed to its popularity and widespread use in various demanding applications.



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Special Application of Nodular Cast Iron: Nodular cast iron, with its exceptional properties, has found special applications in specific industries where its unique characteristics are particularly advantageous. Here are a few notable special applications of nodular cast iron:

1. **High-Pressure and High-Temperature Environments:** Nodular cast iron is often used in applications that involve high-pressure and high-temperature environments. Its excellent strength, thermal conductivity, and resistance to thermal fatigue make it suitable for components such as pressure vessels, engine blocks, exhaust manifolds, and turbocharger housings in industries like automotive, aerospace, and power generation.
2. **Offshore and Marine Environments:** Nodular cast iron's corrosion resistance and high tensile strength make it well-suited for applications in offshore and marine environments. It is commonly used for manufacturing components such as propellers, marine pumps, valves, and offshore platform equipment. The material's resistance to corrosion and its ability to withstand harsh marine conditions contribute to its longevity and reliability.
3. **Heavy-Duty Machinery and Equipment:** Nodular cast iron's high strength, wear resistance, and ability to withstand heavy loads make it an excellent choice for manufacturing heavy-duty machinery and equipment components. It is commonly used for producing gears, gearboxes, crankshafts, hydraulic cylinders, and rollers in industries such as mining, construction, and material handling.
4. **Automotive Brake Components:** The exceptional heat dissipation and wear resistance properties of nodular cast iron make it a preferred material for automotive brake components. Disc brake rotors and brake drums are often manufactured using nodular cast iron due to its ability to withstand the high temperatures and mechanical stresses associated with braking systems. The material's wear resistance ensures consistent and reliable braking performance.
5. **Energy and Power Generation:** Nodular cast iron is widely used in the energy and power generation industry for various applications. It is employed in manufacturing components for turbines, generators, pumps, and valves. The material's strength, thermal conductivity, and resistance to thermal fatigue are vital in these applications, where reliability and efficiency are crucial.
6. **Railroad Industry:** Nodular cast iron is used in the railroad industry for manufacturing rail components such as rail wheels and brake discs. The material's high strength, wear resistance, and ability to withstand heavy loads and impacts make it suitable for the demanding conditions encountered in rail transportation.

These special applications demonstrate how nodular cast iron's unique properties, including its strength, wear resistance, thermal conductivity, and corrosion resistance, can be leveraged in specific industries where these characteristics are essential for optimal performance, durability, and safety.



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Comparison of Nodular Cast Iron with Grey Cast Iron and Steel

Chemical Compositional Differences: The chemical composition of nodular cast iron, grey cast iron, and steel can vary depending on specific grades and specifications. However, the following Table 2 represents typical ranges for each material:

Element	Fe (%)	C (%)	Si (%)	Mn (%)	Mg (%)	S (%)	P (%)	Traces Elements
Grey Cast Fe	Major element	2.5-4.0	1.0-3.0	0.2-1.5	-	<0.1	<1.0	Cu, Ni, Cr, Mo etc.
Nodular Cast Fe	Major element	3.2-4.0	1.8-2.8	0.1-0.5	0.03-0.1	<0.05	<0.1	Cu, Ni, Cr, Mo etc.
Steel	Major element	0.02-2.14	0.15-0.5	0.25-1.5	-	<0.05	<0.05	Cu, Ni, Cr, Ti, Co, V etc.

Table 2: Chemical composition ranges of Nodular Cast Iron, Grey Cast Iron and Steel

It is important to note that these composition ranges are approximate and can vary depending on the specific requirements, standards, and grades of each material. The composition can be adjusted to achieve desired mechanical properties and performance characteristics for different applications.

Micro-structural Differences: Nodular Cast Iron, Grey Cast Iron, and Steel are three distinct materials with different microstructural characteristics. Here are the key differences between them:

- Grey Cast Iron:
 - ✓ Microstructure: Grey cast iron has a microstructure consisting of graphite flakes dispersed in a matrix of ferrite or pearlite.
 - ✓ Graphite Formation: The cooling rate during solidification allows the graphite to form in flake-like shapes. The presence of the graphite flakes contributes to the characteristic gray appearance of this cast iron.
- Nodular Cast Iron (also known as Ductile Iron):
 - ✓ Microstructure: Nodular cast iron has a matrix of ferrite or pearlite with spheroidal graphite nodules dispersed throughout the structure.


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- ✓ Graphite Formation: The addition of nodulizing agents (usually magnesium) during the casting process promotes the formation of graphite nodules rather than flakes, providing improved ductility and toughness.
- Steel:
 - ✓ Microstructure: Steel microstructure depends on the specific type and heat treatment but generally consists of a combination of ferrite, pearlite, martensite, and/or other phases.
 - ✓ Carbon Content: Steel has a lower carbon content compared to cast iron, typically less than 2%. The lower carbon content allows for more varied microstructures and properties based on heat treatment.

In summary, nodular cast iron has a microstructure with spheroidal graphite nodules, providing improved ductility compared to grey cast iron. Grey cast iron contains graphite flakes, resulting in good casting properties and damping capacity. Steel, with its varied microstructures, allows for a wide range of mechanical properties depending on its composition and heat treatment. The below figures are showing the differences of microstructure of Grey Cast Iron, Nodular Cast Iron and Steel.

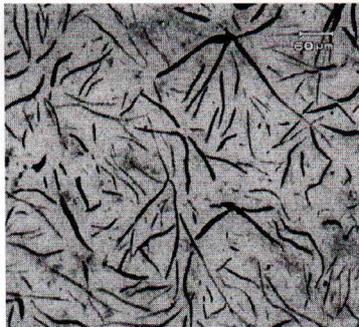


Figure 7: Grey Cast Iron

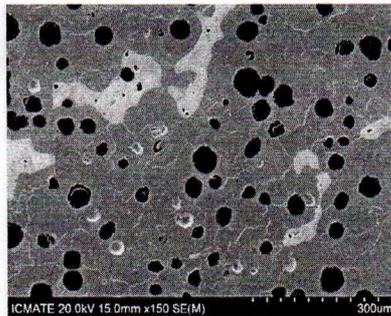


Figure 8: Nodular Cast Iron



Figure 9: Steel

Property Differences: Grey Cast Iron, Nodular Cast Iron and Steel are all types of materials commonly used in various industries and applications. Here's a brief overview of the property variations among these materials:

1. Grey Cast Iron:

- Composition: Grey cast iron contains graphite flakes, which give it its characteristic gray appearance.
- Strength: It has lower tensile strength and yield strength compared to nodular cast iron and steel, making it less ductile.

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- **Hardness:** Grey cast iron is relatively hard but less hard than steel and nodular cast iron.
- **Wear Resistance:** It exhibits good wear resistance due to the presence of graphite flakes.
- **Machinability:** Grey cast iron is generally easy to machine due to the presence of graphite flakes that act as lubricants.

2. Nodular Cast Iron (also known as Ductile Iron or Spheroidal Graphite Iron):

- **Composition:** Nodular cast iron contains graphite nodules or spheroids, which provide it with improved mechanical properties compared to grey cast iron.
- **Strength:** It has higher tensile strength, yield strength, and elongation compared to grey cast iron, making it more ductile and resistant to cracking.
- **Hardness:** Nodular cast iron has a lower hardness than steel but higher than grey cast iron.
- **Wear Resistance:** It exhibits good wear resistance due to the presence of graphite nodules and can withstand abrasive environments.
- **Machinability:** It is more difficult to machine than grey cast iron but generally easier to machine than steel.
- **Damping Capacity:** Damping capacity, also known as damping capability or damping coefficient, refers to the ability of a material or structure to dissipate or absorb energy when subjected to vibrations or oscillations. It is a measure of the material's ability to dampen or reduce the amplitude of vibrations and convert the mechanical energy into heat. Nodular cast iron has excellent damping capacity, making it suitable for applications requiring vibration and noise reduction.

3. Steel:

- **Composition:** Steel is primarily composed of iron and carbon, along with other alloying elements that impart specific properties.
- **Strength:** Steel offers high tensile strength, yield strength, and hardness, providing excellent structural integrity and load-bearing capacity.
- **Ductility:** It is more ductile than both nodular cast iron and grey cast iron, allowing for significant deformation before failure.


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- **Wear Resistance:** Steel can exhibit excellent wear resistance, especially when alloyed with elements such as chromium or tungsten.
- **Machinability:** The machinability of steel varies depending on the specific alloy and hardness, but it is generally good.

It's important to note that within each category, the exact properties can vary based on the specific composition, heat treatment, and manufacturing processes used. These variations allow for the customization of each material to meet specific application requirements.

Nodular Cast Iron Production in BITAC

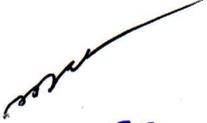
Required Raw Materials and Their Standard Chemical Composition: The following raw materials which were in BITAC for producing Nodular Cast Iron.

- **Cold Rolled Coils and Sheets (CRCA):** (%Fe: 99.2; %C: 0.1 – 0.15; %Si: 0.05; %Mn: 0.4 – 0.6; %P: <0.055; %S: <0.055 etc.)
- **Ferro Silicon (FeSi):** (%Si: 60; %Fe: >21)
- **Ferro Silico Magnesium (FeSiMg):** (%Fe: 46; %Si: 45; %Mg: 5)
- **Graphite Powder** (Efficiency: 80%)
- **Inoculant** (0.2 wt% of Mold Weight)

Alternative Raw Material which can be used instead of CRCA as Prime Scrap:

- **Pig Iron**
 - ✓ **Basic Grade:** (%C: 3.5 – 4.5; %Si: <1.25; %Mn: <1.00; %P: 0.08 – 0.15; %S: <0.05 etc.)
 - ✓ **Foundry Grade:** (%C: 2.8 – 4.2; %Si: 1.0 – 4.0; %Mn: 0.5 – 1.2; %P: <0.12; %S: <0.04 etc.)
 - ✓ **High Purity Grade:** (%C: 3.7 – 4.7; %Si: 0.05 – 1.5; %Mn: <0.05; P: <0.03; %S: <0.025 etc.)


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Steps followed in BITAC for Casting Nodular Cast Iron:

- **Mold Making:** Several number of sand mold was prepared for casting nodular cast iron in shapes of cubic (100mmX50mmX50mm & 60mmX30mmX30mm) and cylindrical (20mm diameter X 600mm length). For making mold, a mixture of 5-6% Sodium Silicate, 2% Wood Powder, 2% Coal Powder and 90% Silica Sand was mixed in a sand mixer machine. CO₂ gas was passed through the mold penetrating by bent wire for making the mold hard and for enabling the deoxidized gas to be removed out from the liquid metal. Inside the cavity of the mold, Mold Cote 11 (Dressing agent) was used for dressing it so that no penetration occurs during pouring the liquid metal into the mold. Then the molds were preheated by gas burner for 10-15 mins.
- **Ladle Making:** A ladle metal carrying capacity of approx. 200kg was prepared. Inside the MS sheet ladle, a mixture of 5-6% Sodium Silicate, 2% Wood Powder, 2% Coal Powder and 90% Silica Sand was applied in a (2-3) inch layer. This ladle was also preheated by gas burner for about 1 hour. This ladle was also dressed by Mold Cote 11 like molds. The bottom portion of the ladle was divided into two parts. FeSi and FeSiMg was kept in one part of the bottom into four layers covering by a MS sheet. Liquid metal was poured into another part of the bottom for avoiding direct reaction with FeSi and FeSiMg. Before that FeSi and FeSiMg was preheated for 1 hour in 200 - 250° C temperature in Core Oven.
- **Furnace & Crucible Preparation:** A total amount of 140kg CRCA and 6.3525kg graphite powder was melted into our 300kg capacity induction furnace. A magnesia crucible was used for melting. CRCA and Graphite Powder was kept in 7 layers into the crucible. At the bottom, 35kg CRCA, above that 2.2kg Graphite Powder, above that 35kg CRCA again, above that 2.1kg graphite powder, above that 35kg CRCA again, above that 2.0525kg Graphite powder and at the top 35kg CRCA was kept into the crucible.
- **Magnesium Treatment and Inoculant Addition:** Magnesium treatment and inoculant addition are commonly used in the production of cast iron, particularly in the context of producing Nodular Cast Iron (NCI), also known as ductile iron. These treatments are performed to modify the microstructure of the cast iron, resulting in improved mechanical properties. Magnesium is added to cast iron to promote the formation of graphite nodules instead of the undesirable flake graphite. The purpose of inoculation is to promote the formation of graphite nodules during solidification. The inoculant provides nucleation sites for graphite growth, resulting in the formation of compact and spherical graphite nodules. Overall, the combination of magnesium treatment and inoculation in the production of Nodular Cast Iron helps optimize the microstructure and mechanical properties of the cast iron, making it more suitable for a wide range of applications where high strength and ductility are required. In our experiment, Magnesium treatment process has been described in the previous Ladle Making step and Inoculant addition process has been described in the following Pouring of Molten Metal into Ladle from Furnace step and Pouring of Molten Metal into Mold from Ladle step.



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- **Pouring of Molten Metal into Ladle from Furnace:** Approximately 0.2kg Inoculant was used in this step. This inoculant was continuously injected during pouring the molten metal from furnace to ladle. This is approximately 65% of total used Inoculant. Before that total 3.8kg FeSi and 2.4kg FeSiMg was kept into the ladle which has been described in Ladle Preparation step in details.
- **Pouring of Molten Metal into Mold from Ladle:** During pouring molten metal from ladle to mold, approx. 0.1kg Inoculant was continuously injected. This is almost 35% of total used Inoculant.
- **Breaking the Mold:** After properly air cooling, the samples were brought out from the cavity of the mold by breaking the molds.
- **Samples Preparation for Testing:** Required number of samples were prepared for the following tests by machining-
 - ✓ Microstructure Test (Both before and after etching)
 - ✓ Chemical Composition Test
 - ✓ Tensile Test
 - ✓ Impact Test

These prepared samples were sent to Bureau of Research, Testing and Consultancy (BRTC), Bangladesh University of Engineering and Technology (BUET) for testing.

Result

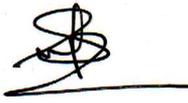
Chemical Composition Test Report: The below Table 3 shows chemical composition report from BUET of our supplied cast iron chips-

Sample Description	Carbon (%)	Silicon (%)	Manganese (%)	Sulphur (%)	Phosphorus (%)	Magnesium (%)
Nodular Cast Iron Chips	4.72	2.95	0.21	0.059	0.030	0.04

Table 3: Chemical Composition of Nodular Cast Iron Casting at BITAC


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Microstructure Test Report: The following Figure 10 and Figure 11 shows the microstructure found in BUET from the supplied samples of BITAC-

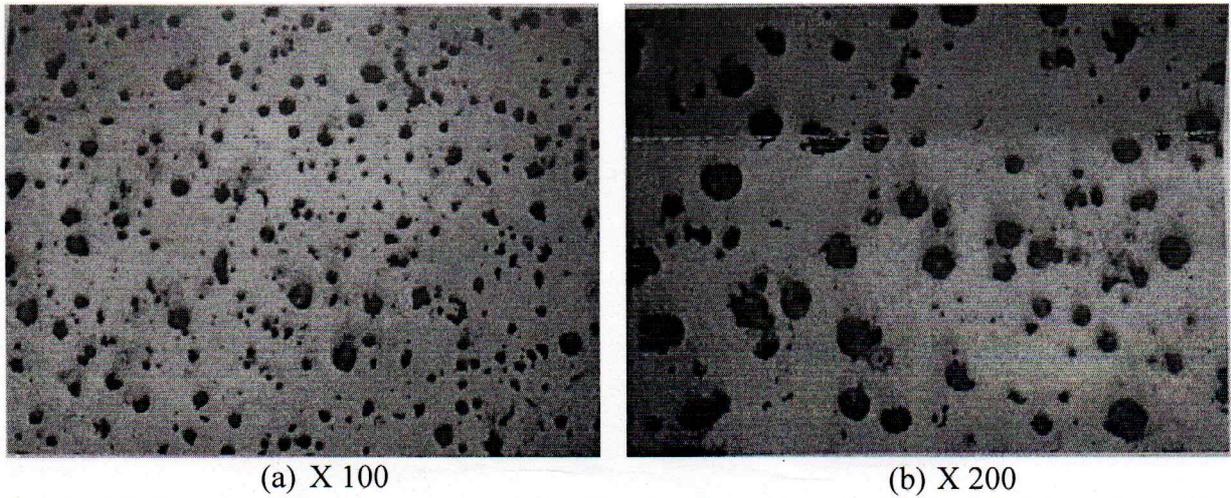


Figure 10: Unetched microstructures of supplied cast iron sample showing nodules of graphite

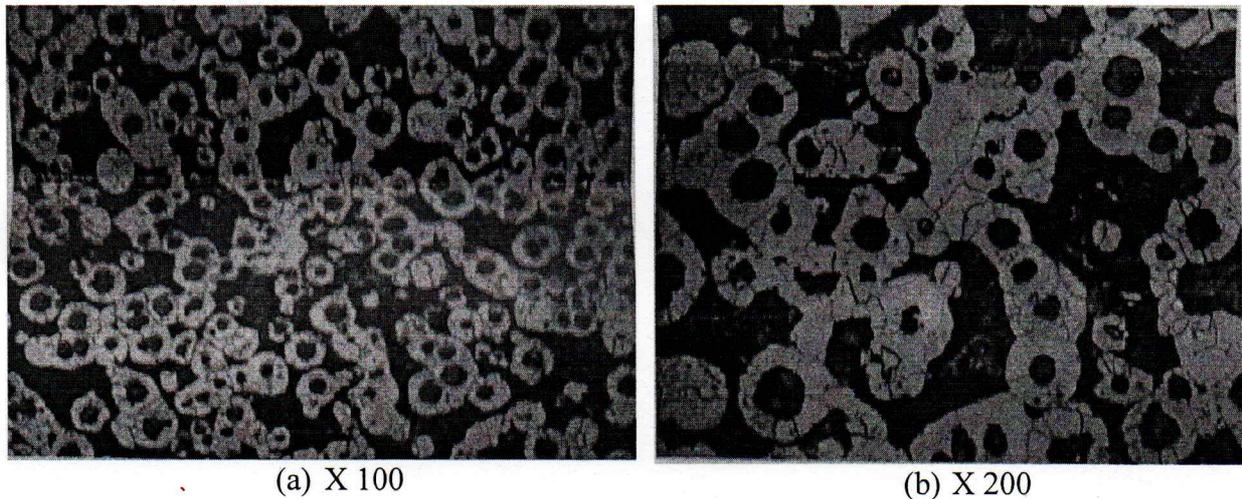


Figure 11: Etched microstructures of the supplied cast iron sample showing nodules of graphite, surrounding ferrite and pearlite grains, which indicate that the sample is a Ferritic Ductile Iron

Tensile Test Report: The following Table 4 represents the tensile test report of BITAC supplied samples from BUET according to ASTM E8 method-

Sample Description	Sample No.	Yield Strength (MPa)	Tensile Strength (Mpa)	Ratio (Tensile/ Yield)	Elongation (%) Gauge Length 50mm
Cast Iron Round Bar	1	410	471	1.148	3
	2	428	544	1.271	3
	3	453	580	1.280	4
	Average	430	532	1.237	3.33

Table 4: Tensile Test Report of Nodular Cast Iron Casting at BITAC


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Impact Test Report: The following Table 5 represents the impact test report of BITAC supplied samples from BUET according to ASTM A327 method-

Sample Description	Test Type	Test Temperature (°C)	Absorbed Impact Energy (J)	
			Individual Reding	Average Value
Cast Iron Round Bar	Charpy Test Bar Notched Sample	30	12, 12, 14, 13	13

Table 5: Impact Test Report of Nodular Cast Iron Casting at BITAC

Comparison of Nodular Cast Iron with Grey Cast Iron and Steel

Comparison According to Tensile Property: The following Table 6 represents the ranges of standard Yield Strength, Tensile Strength value for Nodular Cast Iron, Grey Cast Iron, Steel and samples casted in BITAC.

Tensile Property	Grey Cast Iron	Nodular Cast Iron	Steel	BITAC Produced Nodular Cast Iron
Yield Strength (MPa)	175 - 300	370 - 600	200 - 600	430
Tensile Strength (MPa)	250 - 400	550 - 800	300 - 800	532
References	ISO 185 ASTM A48 BS 1452	ISO 1083 ASTM A536 BS EN 1563	Carbon Steel Low Alloy Steel High Strength Steel	

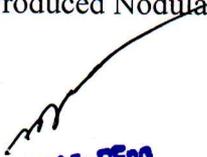
Table 6: Standard Tensile Property Comparison of Grey Cast Iron, Nodular Cast Iron, Steel and BITAC Produced Nodular Cast Iron

Comparison According to Absorbed Impact Energy: The following Table 7 represents the ranges of standard value of Absorbed Impact Energy for Grey Cast Iron, Nodular Cast Iron, Steel and samples casted in BITAC according to Charpy Test method at 30°C temperature-

Material	Test Method	Test Temperature (°C)	Absorbed Impact Energy (J)
Grey Cast Fe	Charpy Test	30	3 - 10
Nodular Cast Fe			10 - 20
Steel			20 - 100
BITAC Produced Nodular Cast Fe			13

Table 7: Standard Absorbed Impact Energy Comparison of Grey Cast Iron, Nodular Cast Iron, Steel and BITAC Produced Nodular Cast Iron


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Conclusion

In conclusion, the research and development project conducted at BITAC aimed to establish a general procedure for producing Nodular Cast Iron (NCI) from traditional steel scrap available in Bangladesh and to provide a comparative analysis with Grey Cast Iron (GCI) and Steel. Throughout the project, extensive research, experimentation, and analysis were carried out to understand the feasibility and potential benefits of utilizing steel scrap as a raw material for NCI production.

The project successfully achieved its objectives by developing a systematic procedure for transforming steel scrap into NCI, which involved specific steps such as scrap selection, pretreatment, alloying, and casting. This procedure demonstrated promising results in terms of producing NCI with desirable mechanical properties, including improved tensile strength, ductility, and impact resistance compared to GCI.

The comparative analysis revealed that NCI exhibited superior properties when compared to both GCI and Steel. It showcased enhanced strength and toughness similar to steel. This makes NCI a valuable material for various industrial applications, particularly in sectors such as automotive, machinery, and infrastructure.

The findings of this research and development project have significant implications for the manufacturing industry in Bangladesh. By utilizing traditional steel scrap, which is abundantly available, the country can reduce its dependency on expensive imported raw materials for cast iron production. This can lead to cost savings, resource conservation, and improved sustainability in the long run.

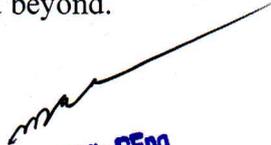
Furthermore, the project contributes to the overall advancement of material science and engineering by expanding the understanding of NCI production techniques and highlighting the potential of steel scrap as a viable raw material. The established procedure can serve as a valuable reference for researchers, engineers, and industry professionals involved in the production of NCI.

However, it is important to note that further research and development efforts are necessary to optimize the process, fine-tune the parameters, and ensure scalability and commercial viability. Additionally, considerations must be given to the environmental impact of the procedure and the sustainability of the entire production cycle.

In conclusion, the research and development project conducted at BITAC successfully established a general procedure for producing Nodular Cast Iron from traditional steel scrap available in Bangladesh. The comparative analysis demonstrated the superior properties of NCI compared to Grey Cast Iron and Steel, making it a valuable material for various industrial applications. The project's outcomes have significant implications for the manufacturing industry, offering cost savings, resource conservation, and improved sustainability. Further research is needed to refine the process and address environmental considerations, paving the way for wider adoption of Nodular Cast Iron production in Bangladesh and beyond.



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Appendices

Appendix A - Recipe Calculation using CRCA as Prime Scrap

Appendix B – Microstructure Test Report from BRTC, BUET

Appendix C – Chemical Composition Test Report from BRTC, BUET

Appendix D – Tensile Test Report from BRTC, BUET

Appendix E – Impact Test Report from BRTC, BUET



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Recipe Calculation using CRCA as Prime Scrap

The following Table 8 represents the composition we require for casting our Nodular Cast Iron-

Element	Fe	C	Si	Mn	Mg
Required Composition (%)		3.5	2.3	0.15	0.08

Table 8: Required Composition of Nodular Cast Iron for Casting in BITAC

Total Product Weight: 150kg

C requires: $((3.5 \times 150)/100) = 5.25\text{kg}$

Si requires: $((2.3 \times 150)/100) = 3.45\text{kg}$

Mn requires: $((0.15 \times 150)/100) = 0.225\text{kg}$

Mg requires: $((0.08 \times 150)/100) = 0.12\text{kg}$

Fe requires: $(150 - 5.25 - 3.45 - 0.22 - 0.12) = 140.96\text{kg}$

Inoculant requires: $((150 \times 0.2)/100) = 0.3\text{kg}$

From 140kg CRCA-

Fe = $((99.2 \times 140)/100) = 138.88\text{ kg}$

C = $((0.12 \times 140)/100) = 0.168\text{ kg}$

Mn = $((0.5 \times 140)/100) = 0.7\text{ kg}$

Si = $((0.05 \times 140)/100) = 0.07\text{ kg}$

Extra Element requires-

Fe = $(140.96 - 138.88) = 2.08\text{ kg}$

C = $(5.25 - 0.168) = 5.082\text{ kg}$

Si = $(3.45 - 0.07) = 3.38\text{ kg}$

Mg = 0.12 kg

For 0.12 kg Mg, FeSiMg requires = $((100 \times 0.12)/5) = 2.4\text{ kg}$

From 2.4 kg FeSiMg-

Mg = 0.12kg

Si = $((2.4 \times 45)/100) = 1.08\text{ kg}$

Fe = $((2.4 \times 46)/100) = 1.104\text{ kg}$

Extra Element requires-

Fe = $(2.08 - 1.104) = 0.976\text{ kg}$

Si = $(3.38 - 1.08) = 2.3\text{ kg}$

C = 5.082 kg

For 2.3kg Si, FeSi requires = $(100 \times 2.3)/60) = 3.8\text{ kg}$

From 3.8kg FeSi-

Si = 2.3kg

Fe = $((21 \times 3.06)/100) = 0.6426$

Extra Element requires-

Fe = $(0.976 - 0.6426) = 0.3334\text{ kg}$

C = 5.082 kg

For 5.082kg C, Graphite Powder requires = $((100 \times 5.082)/80) = 6.3525\text{kg}$

From 6.3525kg graphite Powder-

C = 5.082 kg

Extra Element Requires-

Fe = 0.334 kg

Recipe for 150kg Nodular Cast Iron-

CRCA = 140kg

FeSiMg = 2.4kg

FeSi = 3.8 kg

Graphite Powder = 6.3525 kg

Inoculant = 0.3kg



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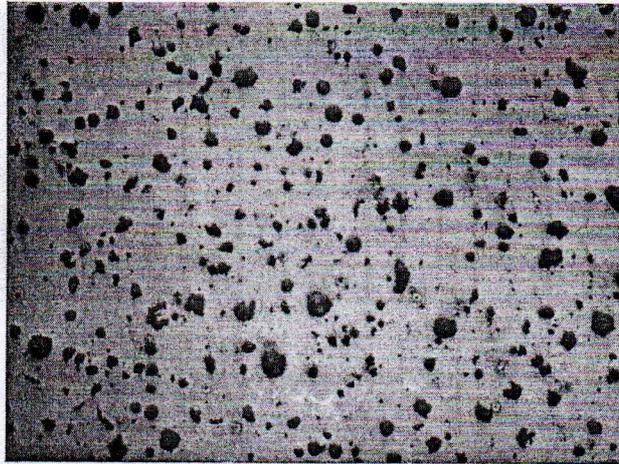
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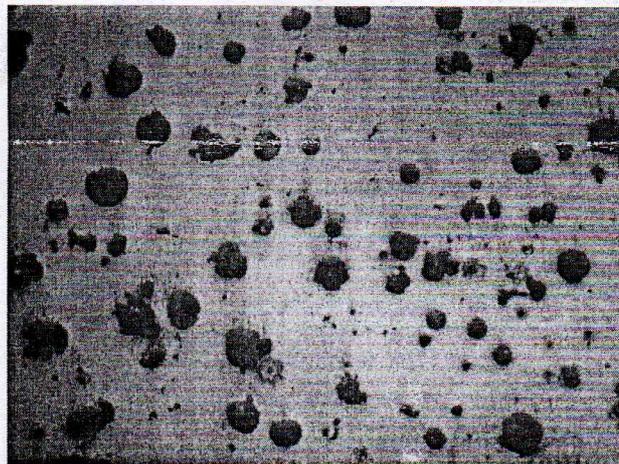
Client's Reference : 36.06.2692.029.44.495.23/1238; Date 11/06/2023
BRTC Reference : 1102-93426/MME/2022-23; Date 11/06/2023
Subject : Metallographic Test of Cast Iron
Sample Condition : Not Sealed

Please Note: The client supplied the sample and the result given herewith corresponds to the sample tested only. The Department of Materials and Metallurgical Engineering of BUET takes no responsibility regarding the misidentification, if any, of the sample.

TEST REPORT



(a)



(b)

Unetched microstructures of the supplied cast iron sample showing nodules of graphite. (a) $\times 100$; (b) $\times 200$.

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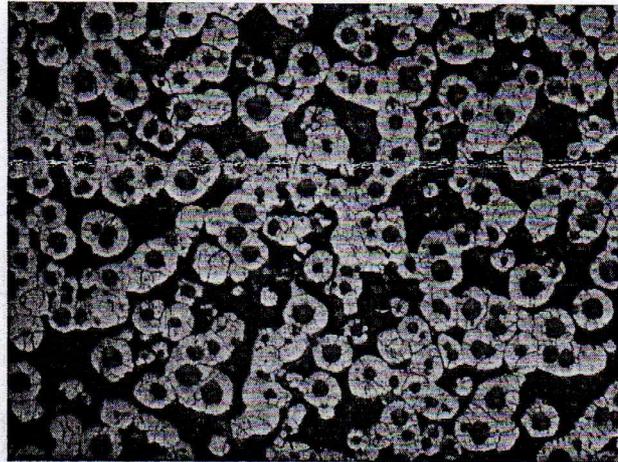
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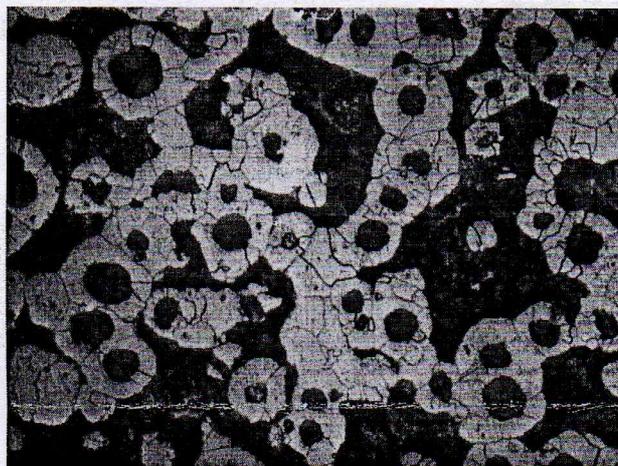


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BRTC Reference : 1102-93426/MME/2022-23; Date 11/06/2023

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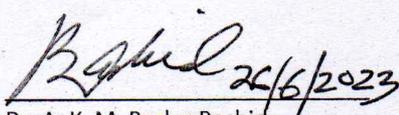


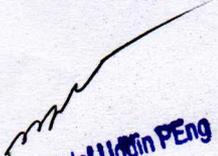
(a)



(b)

Etched microstructures of the supplied cast iron sample showing nodules of graphite, surrounding ferrite, and pearlite grains, which indicate that the sample is a Ferritic Ductile Iron. (a) $\times 100$; (b) $\times 200$.


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Page 2 of 2



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Client's Reference : 36.06.2692.029.44.495.23/1237; Date 11/06/2023

BRTC Reference : 1102-93433/MME/2022-23; Date 11/06/2023

Subject : Test of Cast Iron

Sample Condition : Not Sealed

08 July 2023
MME-1383/2022-23



Please Note: The client supplied the sample and the result given herewith corresponds to the sample tested only. The Department of Materials and Metallurgical Engineering of BUET takes no responsibility regarding the misidentification, if any, of the sample.

TEST REPORT

Chemical Composition Test

Sample Description	Chemical Composition, wt.%					
	Carbon	Silicon	Manganese	Sulphur	Phosphorus	Magnesium
Cast Iron Chips	4.72	2.95	0.21	0.059	0.030	0.04

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26 June 2023
MME-1382/2022-23



Client's Reference : 36.06.2692.029.44.495.23/1235; Date 11/06/2023
BRTC Reference : 1102-93431/MME/2022-23; Date 11/06/2023
Subject : Test of Cast Iron
Sample Condition : Not Sealed

Please Note: The client supplied the sample and the result given herewith corresponds to the sample tested only. The Department of Materials and Metallurgical Engineering of BUET takes no responsibility regarding the misidentification, if any, of the sample.

TEST REPORT

Tensile Test Report

Sample Description	Sample No.	Test Method	Yield Strength, MPa		Ultimate Tensile Strength, MPa		Elongation at Break, % (G.L. 50 mm)	
			Readings	Average	Readings	Average	Readings	Average
Cast Iron Round Bar	1	ASTM E8	410	430	471	532	3	3.33
	2		428		544		3	
	3		453		580		4	

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MME-1380/2022-23



Client's Reference : 36.06.2692.029.44.495.23/1236; Date 11/06/2023
BRTC Reference : 1102-93422/MME/2022-23; Date 11/06/2023
Subject : Test of Cast Iron
Sample Condition : Not Sealed

Please Note: The client supplied the sample and the result given herewith corresponds to the sample tested only. The Department of Materials and Metallurgical Engineering of BUET takes no responsibility regarding the misidentification, if any, of the sample.

TEST REPORT

Impact Test Report

Sample Description	Test Method	Test Type	Test Temperature, °C	Absorbed Impact Energy, J	
				Individual Reading	Average Value
Cast Iron Round Bar	ASTM A327	Charpy Test Bar Notched Sample	30	12, 12, 14, 13	13

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