“Investigation on the effect of alloying elements addition and solidification time on nodularity on 400/15 SGI casting”

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CERTIFICATE

It is certified that the work contained in the dissertation thesis entitled **"Investigation on the effects of alloying elements addition and solidification time on nodularity on 400/15 SGI casting"** submitted by **Mr. DURGESH R. THUMAR** ENROLLMENT NO **180044006**, studying at Mechanical Engineering Department, Faculty of Engineering & Technology, for the award of M.Tech Mechanical Engineering (Production) is absolutely based on his own work carried out under our supervision and this thesis has not been submitted elsewhere for any degree.

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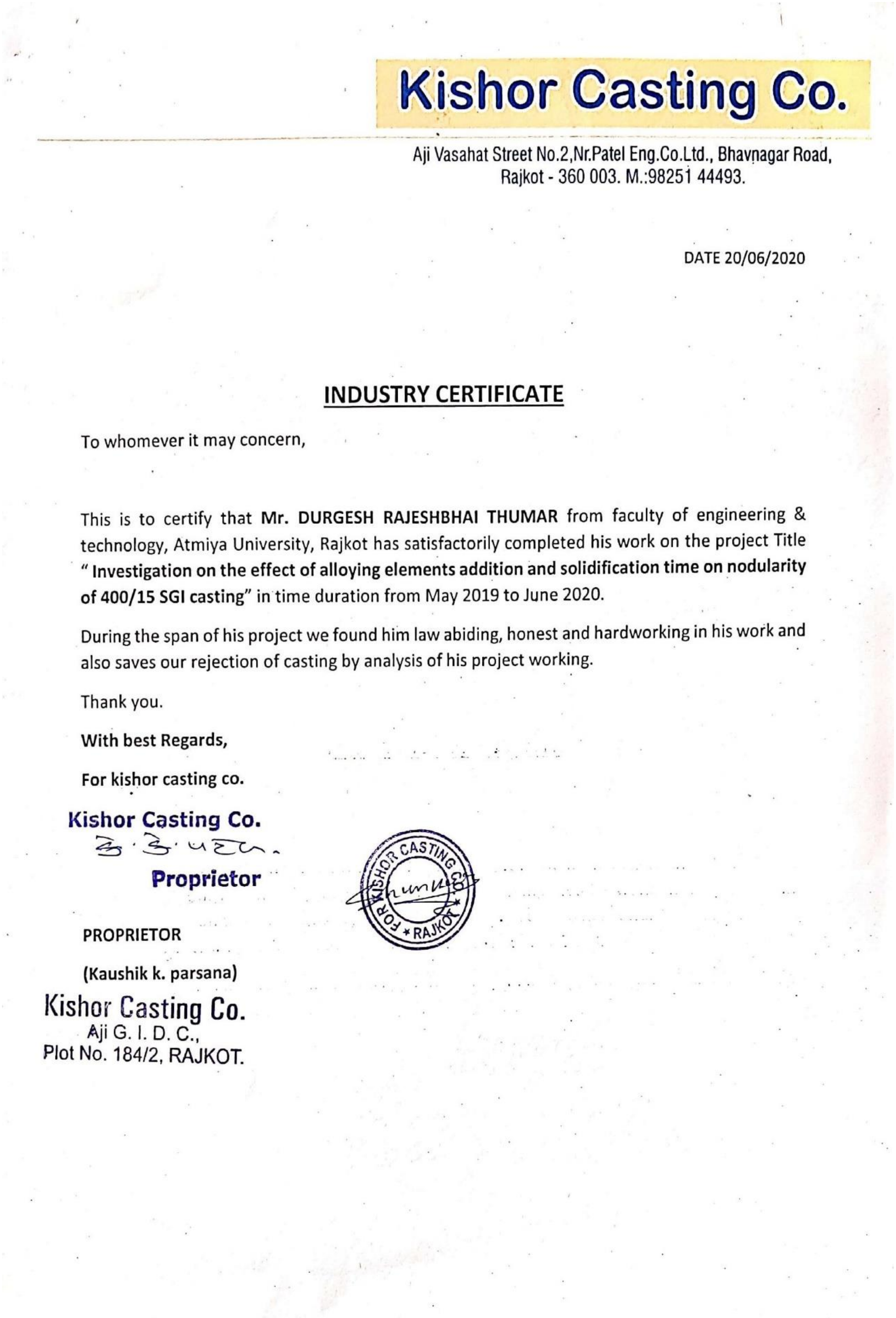

Kishor Casting Co.

Aji Vasahat Street No.2,Nr.Patel Eng.Co.Ltd., Bhavnagar Road,
Rajkot - 360 003. M.:98251 44493.

DATE 20/06/2020

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To whomever it may concern,

This is to certify that **Mr. DURGESH RAJESHBHAI THUMAR** from faculty of engineering & technology, Atmiya University, Rajkot has satisfactorily completed his work on the project Title **" Investigation on the effect of alloying elements addition and solidification time on nodularity of 400/15 SGI casting"** in time duration from May 2019 to June 2020.

During the span of his project we found him law abiding, honest and hardworking in his work and also saves our rejection of casting by analysis of his project working.

Thank you.

With best Regards,

For kishor casting co.

Kishor Casting Co.
ક. ક. પરસાણા.
Proprietor

FOR KISHOR CASTING CO. ★ RAJKOT

PROPRIETOR

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PAPER PUBLICATION CERTIFICATE

This is to certify that research work embodied in this dissertation titled **“Investigation on the effects of alloying elements addition and solidification time on nodularity on 400/15 SGI casting”** was carried out by **Mr. DURGESH R. THUMAR (En. No. 180044006)** at **Faculty of Engineering & Technology, Rajkot (051)** for partial fulfillment of Master of Technology degree to be awarded by Atmiya University has published review article **“Effect of alloying elements addition and solidification time on nodularity of 400/15 SGI casting-A review”** for publication in the **“Trends in Mechanical Engineering & Technology, Volume 10 Issue 3, 2020.”**

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DURGESH R. THUMAR
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NOMENCLATURE

SGI	Spheroidal Graphite Iron
CI	Cast Iron
Mg	Magnesium
Mn	Manganese
Si	Silicon
S	Sulfur
BHN	Brinell Hardness Number

"Investigation on the effect of alloying elements addition and solidification time on nodularity on 400/15 SGI casting"

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ABSTRACT

A spheroidal graphite iron (SGI) is widely accepted material for the casting process. It is also known as graded casting and researcher claims that it is difficult to maintain the proportion of the elements and its composition. One of the ways to control it in the required way, the micro-structural analysis is becomes necessity. The current research is addressing the impact of different alloying elements and mould opening time (self-annealing) of SG 400/15 grade cast iron. The general measures in term of microstructure analysis is nodularity, to maintain its required counts as per the specific application is depends on the alloying elements and solidification times and many other parameters. In SGI, nodularity is the strong function of the mechanical properties of the product. In the current research, the efforts have been made to establish a relationship between nodularity and proportion of alloying elements including magnesium, manganese, sulfur, silicon and other important process parameters i.e. pouring temperature, pouring time and mould opening time.

Keywords: SGI 400/15 grade, Nodularity, Solidification time, Alloying Elements, pouring temperature, pouring time.

CHAPTER 1

INTRODUCTION

1.1 Background:

- Casting is defined as a “metal object obtained by allowing molten metal to solidify in a mold”.
- Most intricate shapes, both external and internal, maybe cast. As a result, many other operations, such as machining and welding, maybe minimized or eliminated.
- Now a day, due to strong competition in the market to achieve higher efficiency for all automobile parts. Sound quality casting is required. Quality of the casting is affected by many parameters. [2]

1.2 How is S.G Cast Iron Produced?

- It is produced by treating the molten alloy with magnesium, or cerium, or a combination of two elements, or such elements like Ca, Ba, Li, causing spheroidal graphite to grow during solidification.
- Use of magnesium to have 0.04-0.06% residual content is more easy to adopt and economical, which is followed by addition of Ferro-silicon. Certain elements, if present, like 0.1% Ti, 0.009% Pb, 0.003% Bi, 0.004% Sb prevent the production of S.G iron, but their effect can be removed by adding 0.005-0.01% Ce.
- For most raw materials, combined use of Mg and Ce (it improves magnesium recovery) followed by Ferro silicon as inoculant is made to produce S.G Iron.
- A 1% addition of silicon raises the proof and tensile strength of a ferritic iron by approximately 82 N/mm2 whereas 1% of nickel increases these properties by 46 N/mm^2.[5]
- Austempered Cast Iron, which shows very good combination of properties.
- Desulphurization: Sulphur helps to form graphite as flakes. Thus, the raw material for producing S.G Iron should have low Sulphur (less than 0.1%), or remove Sulphur from iron during melting, or by mixing iron with a desulphurising agent

such as calcium carbide, or soda ash (sodium carbonate).

- Magnesium is added when melt is near 1500 degree centigrade, but magnesium vaporizes at 1150 degree centigrade. Magnesium being lighter floats on the top of the bath, and being reactive burn off at the surface. In such cases magnesium is added as Ni-Mg, Ni-Si-Mg alloy or magnesium coke to reduce the violence of the reaction and to have saving in Mg.
- Inoculation: As magnesium is carbide former, ferrosilicon is added immediately as inoculant. Remelting causes reversion to flake graphite due to loss of magnesium. Stirring of molten alloy after addition of nodulising element evolves a lot of gas, which gets dissolved in liquid alloy, and forms blow-holes in solid casting. The contraction during solidification of nodular cast iron castings is much greater than that of gray iron castings, which needs careful design of moulds to avoid shrinkage cavities in solidified castings.[7]

1.3 AVERAGE COMPOSITION OF S.G. CAST IRON:[8]

- Carbon – 3.0 - 4.0 %
- Silicon – 1.8 – 2.8 %
- Manganese – 0.1 – 1.00 % Sulphur – 0.03% max.
- Magnesium – 0.01 – 0.10 %

1.4 Effect of alloying elements on the properties of ductile iron:

- Silicon: As the Si in the ductile iron, matrix provides the ferrite matrix with the pearlitic one.
- Copper: It is a strong pearlite promoter. It increases the proof stress with also the tensile strength and hardness with no embrittlement in matrix.
- Nickel: As it helps in increasing the U.T.S without affecting the impact Values.
- Molybdenum: It is a mild pearlite promoter. Forms intercellular carbides especially in heavy sections. Increases proof stress and hardness.
- Chromium: As it prevents the corrosion by forming the layer of chromium oxide on the surface and stops the further exposition of the surface to the atmosphere.
- Sulphur and Phosphorus: As ‘P’ is kept intentionally very low, as it is not required

because it causes cold shortness and so the property of ductile iron will be ruined[9]

1.5 Magnesium treatment:

- Why magnesium research work has shown that on a laboratory scale additions of a number of elements are capable of producing spheroidal graphite structures in the cast irons. These elements include magnesium, cerium, calcium and yttrium.
- Japan calcium based alloys are used for producing ductile iron castings. [10]

1.6 Carbide in the structure: [11]

- S.G iron castings are more prone to contain carbides than flake-graphite castings of similar section, size, carbon, and silicon contents.
- The presence of carbide in ductile iron is undesirable for a number of reasons:
- It increases the tendency to form shrinkage porosity and thus increases the feeding requirements during casting.
- Increases the risk of cracking during knockout and fettling.
- Decreases the ductility of the iron.
- Drastically reduces the impact resistance.
- Increases hardness and reduces machinability.
- It requires heat treatment to 900-920^{0}C to remove the carbide.

1.7 APPLICATIONS: [12]

The possible applications of S.G Iron are very wide

- Support bracket for agricultural tractor.
- Tractor life arm.
- Check beam for lifting track.
- Mine cage guide brackets.
- Gear wheel and pinion blanks and brake drum.
- Machines worm steel.
- Flywheel.
- Thrust bearing.
- Frame for high-speed diesel engine.

- Four throw crankshaft.
- Fully machined piston for large marine diesel engine.
- Bevel wheel.
- Hydraulic clutch on diesel engine for heavy vehicle.
- Fittings overhead electric transmission lines.
- Boiler mountings, etc.

1.8 HEAT TREATMENT

- Nodular cast irons (or ductile, or spheroidal graphite iron) are primarily heat treated to create matrix microstructures and associated mechanical properties not readily obtained in the as-cast condition. As-cast matrix microstructures usually consist of ferrite, pearlite, or combinations of both, depending on cast section size and/or alloy composition.
- The principle objective of the project is to carry out the heat treatment of SG cast Iron and then to compare the mechanical properties.
- There are various types of heat treatment processes we had adopted.[13]

ANNEALING

a) The specimen was heated to a temperature of 900 degree Celsius.
b) At 900 degree Celsius, the specimen was held for 2 hour.
c) Then the furnace was switched off so that the specimen temperature will decrease with the same rate as that of the furnace.

The objective of keeping the specimen at 900 deg. Celsius for 2 hrs. is to homogenize the specimen. The temperature 900 deg. Celsius lies above Ac1 temperature. So that the specimen at that temperature gets sufficient, time to get [11]

1.9 Product Detail:

Fig-1.1 Product casting cap

- This product is called as the casting cap, which is used in railway electrical poles insulators.
- The main function of this product is to provide sufficient elongation or tensile stress, which is the major requirement of this product.
- Therefore, we need to maintain its elongation capacity above the breaking limit of this material.
- The detailed specification of this product is as shown in the below table.

Table 1.1: Product detail

Material	SGI 400/15 BS2789 EN1563 ISO 9001:2015
Unit weight	1.5 kg
Size of the casting box	Cope: 500×470×110 mm Drag: 500×470×65 mm
Shape of casting box	Rectangular
Type of gating system	Non pressurize
Moulding sand	Green sand
Pouring temperature	1300 ˚C to 1400 ˚C

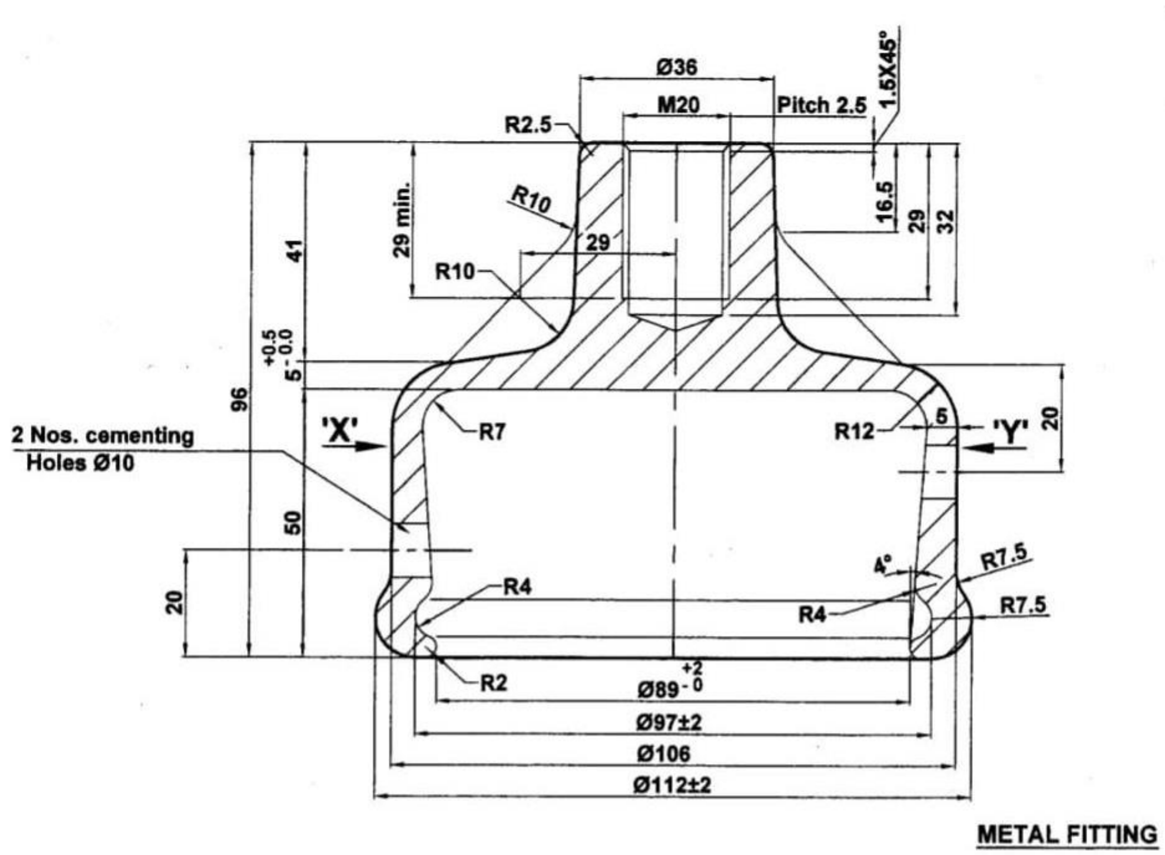


Fig -1.2 company part drawing

1.10 Company pattern:thi

Fig 1.3 Pattern of cope

Fig 1.4 Pattern of drag

Table 1.2: chemical composition [15]

Element	Specified Content (%)	Actual Content (%)
Carbon(C)	3.40-3.85	3.8
Manganese (Mn)	0.10-0.30	0.21
Silicon(Si)	2.10-2.30	2.25
Sulphur (S)	0.020 max	0.016
Phosphorous(P)	0.10 Max	0.03
Magnesium(Mg)	0.07 Max	0.002
Iron(Fe)	Remaining	Remaining

1.11 Current Heat Treatment Cycle:

1. Preheating up to 860 degrees centigrade – 8 hours (108 degrees per hour rise).
2. Shocking – 1 & ½ hours.
3. Cooling up to 650 degrees centigrade – 2 & ½ hours.
4. Total – 12 hours. Cycle close & Open the material. [10]

1.12 Nodularity relation with mechanical property

It is concluded that all properties relating to strength and ductility decrease as the graphite nodularity increase, and those properties relating to failure, such as tensile strength and impact strength are more affected by changing of graphite nodularity. The minimum graphite nodularity of 60% can be considered for design as satisfactory values of ductile iron fittings and accessories for all DN values. [9]

Automation of Heat Treatment Process using PLC and Lab VIEW

Annealing:

In annealing process, cooling rate is very slow around 10°C per hour. This Process is carried out in a controlled atmosphere of inert gas to avoid oxidation, which is used to reach ductility in work-hardened steels. Annealing is performed to reduce hardness, remove residual stresses, improve toughness, restore ductility, and to alter various mechanical, electrical or magnetic properties of material through refinement of grains

Annealing: Annealing is a process of heating the metal to a temperature above the austenizing temperature for sufficient time as long as the material transforms into austenite or austenite cementite & then cool slowly at the rate of about 20ºC/hr. Annealing is performed to improve the ductility of material so that it can be mechanically processed more easily by other processes.

Purpose: Softening, and removing residual stress for post processes [8]

Ductility

Ductility is a dimensionless quantity commonly defined as the ability of a material to deform easily upon the application of a tensile force, or as the ability of a material to withstand plastic deformation without rupture. Ductility is an important factor in allowing a structure to survive extreme loads, such as those due large pressure changes, earthquakes and hurricanes, without experiencing a sudden failure or collapse. It is defined as:

$$\text{Percentage elongation} = \left(\frac{L_{f-}\,L_{o}}{L_{0}}\right) \text{x } 100$$

Where,

- Lf is the length of the specimen when it finally rupture (or breaks)
- Lo is the original gauge length of the specimen

Tensile strength is measured in units of force per unit area. The unit is newton per square meter (N/m^2). [9]

CHAPTER 2

LITERATURE REVIEW

Y Qiu, JC Pang et. al.; [1] this research studies the effects of titanium added in an amount up to 0.13 wt. % on the microstructure and mechanical properties. The research was conducted for thin-walled iron castings with 3-5 mm wall thickness and for the reference casting with 13 mm wall thickness to achieve various cooling rates. Microstructural changes were evaluated by analyzing quantitative data sets obtained by image analyzer and also using scanning electron microscope. Metallographic examination revealed in thin-walled castings a significant effect of the addition of Ti to compacted graphite, much stronger in comparison with castings with thicker sections. Moreover, thin-walled castings with high degrees of inoculation and which have been solidified under high cooling rates have a homogeneous structure, free of chills, and good mechanical properties, which may predispose them for potential use as substitutes for aluminum alloy castings in diverse applications**.** From the experiments it is concluded that even at Mg levels as low as 0.01% it is not possible to obtain acceptable fraction of compacted graphite in thin-walled castings (G £ 5 mm) because of excessive nodularity. The introduction of Ti in amounts up to 0.13% iron allows a high proportion of compacted (vermicular) graphite in thin-walled castings**.**

Sertucha, Jon & Lacaze et. al.; [2] the development of low temperature applications for ferritic nodular cast irons calls for improved materials in the as cast state, e.g. for off-shore windmills components. Within this line of work, a series of 68 castings were prepared with the same casting procedure and slight changes in composition. The tensile properties at room temperature, as well as the impact energy for rupture at room temperature, 220uC and 240uC, were measured. Outputs from multivariate analysis performed on the data are then discussed and compared to literature results, putting emphasis on the properties of the ferritic matrix. Statistical analysis of all as cast alloys prepared in the present work, with pearlite fraction from 0 to 35%, confirmed the effects of silicon and nickel on RT tensile properties and hardness and that of silicon on impact properties at RT, 220uC and 240uC. Investigating either all as cast alloys or only the fully ferritic ones, silicon was found to have similar effects with those reviewed in the introduction. That is, UTS, Y and hardness increase and both A and impact energy any case, it was observed that higher nodule counts slightly increase elongation at rupture and impact energies, though this latter effect is more marked at lower temperatures.

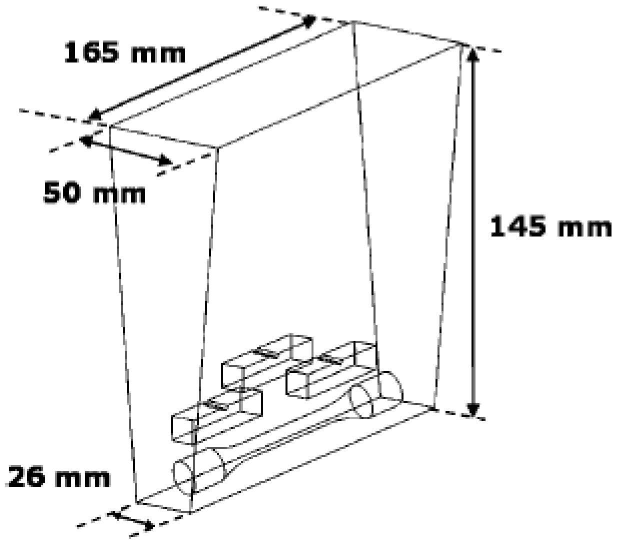


Fig2.1 Keel block used for all castings showing locations where mechanical test samples were machined

Oluwole, Leke & Olorunniwo et. al.; [3] this study investigated the effect of magnesium and calcium as spheroidizers on the graphite microstructure in cast iron. The cast iron samples were melted in an induction furnace with charge of known composition and, magnesium and calcium of known percentages were added as spheroidizers to the molten metal in the mould during the casting process. From the microstructure of the as- cast specimens it was observed that the use of 100% Mg and a combined addition of 60% and 40%Ca as spheroidizers produced graphite spheroids instead of graphite flakes in the cast iron microstructure. The use of 100% Ca addition resulted in the production of graphite flakes in the specimen microstructure. The use of 80% Mg and 20% Ca resulted in the production of a chunky, stubby graphite microstructure, while the additions of 50% Mg and 50% Ca, 40%Mg and 60% Ca, and 20% Mg and 80% Ca resulted in the microstructure having a flaky graphite microstructure. On the strength of the results obtained from this research, the following conclusions were made: The use of magnesium as a spheroidzing agent produces spheroidal graphite cast iron having microscopic nodular graphite grains. These nodules have a minimum effect on the mechanical properties of the cast iron. The mechanical properties are mainly determined by the type of matrix structure and this imparts the favorable physical properties of cast iron (low melting point, good fluidity and castability), with the engineering advantages of steel (high strength, toughness, ductility, hot workability and hardenability). The use of calcium as a spheroidzing agent produces grey flake cast iron. The mechanical properties of the cast iron produced are influenced by the graphite flakes. The use of a combined addition of 60% Mg and 40% Ca as spheroidzing agent in an in- mould addition technique produces spheroidal graphite cast iron. This combined addition reduces the amount of Mg alloy used in the spheroidization process thereby reducing cost of production. The small shape of the nodule produced as shown in plate 4 also increases the nodularity of the cast iron. The use of other varying combined addition produces graphite flakes in the cast iron microstructure.

Serrallach, Joan & Lacaze et. al.; [4] there is a continuous demand for low-cost nodular cast irons with improved mechanical properties, this being an industrial requirement both for pearlitic as well as for ferritic grades. Developments in pearlitic nodular irons should lead to alloys with higher and higher strength while retaining some ductility in the as-cast state so as to respond to demands related to castings for high power automotive engines in competition with steel castings and ADI. According to these aims, several alloying elements have been selected and added separately or combined to standard commercial nodular cast irons. In all cases, only low-level additions were made and their effects on the microstructure and mechanical properties at room temperature have been characterized and are discussed. A statistical analysis has been performed on the data obtained that accounts for changes in alloying additions as well as for variations in process parameters

Table 2.1: Composition of charges in percentage

Charge	C	Si	Mn	S	P
Cast iron scrap	3.2	2.0	0.5	0.03	0.01
Mild steel scrap	0.2	0.2	0.8	0.08	0.01
Carburizer	99.93	-	-	-	-
Ferrosilicon	-	75.0	-	-	-

Table2.2: Charge Calculation for two metric tons metals

Charge	Mass (kg)	%	C	Si	Mn	S	P
Cast iron scrap	1200	60	1.92	1.20	0.3	0.018	0.006
Mild steel scrap	740	38.5	0.077	0.077	0.308	0.0308	0.0308
Carburizer	30	1.5	1.499	-	-	-	-
Total	2,000	100	34.496	1.277	0.608	0.0488	0.0099

The statistical analysis performed in this work allows mechanical properties of a specific alloy to be predicted as a function of the square root of the cooling rate (Vr), structural features and the alloy's composition. As expected, an increase in the ferrite fraction decreases LE, UTS and D, and increases slightly rupture elongation. The most noticeable effect is that of the cooling rate which dramatically affects tensile and yield strengths as well as hardness

Imre KISS; Sorin RATIU; et. al.; **[5]** the technical conditions, which are imposed to the cast iron rolls in the exploitation period, are very different and often contradictory. The obtaining of various physical and mechanical properties in the different points of the same foundry product meets difficult technological problems in the industrial condition. This supposes us to know many technological factors, which lead to this deformation equipment

Ingole, P. P. M., Awate et.al; **[6]** the basic chemical element such as carbon, 0silicon, manganese, magnesium, copper etc. plays an important role in SGI (Spheroidal Graphite Iron) castings process. The behavior of these elements in molten metal of the ductile iron plays a different role because of their different mechanical and chemical properties. If we govern such composition that will be optimal by virtue of its study of effects on castings. As we know, there is small change in the chemical composition, the wide effects on the mechanical properties and their microstructure. The chemical compositions in ductile iron are always considered in the range. So that it is difficult to achieve the targeted mechanical properties and the microstructure as per the given specification it always affects in the end use of the product

Peng, Y. C., Jin, H. J et. al.; [7] Different cooling rates of salt-bath furnace were obtained by adding different water contents, which affects the microstructure and mechanical properties of CADI. It was found that the higher the water volume added to the salt bath, the higher the hardness of CADI. The highest hardness of the sample was obtained when the water content is approximately 3%. However, the impact toughness decreased gradually as the water increased. 3. The percentage content of retained austenite was altered by different cooling rates, and the cooling rate had a great impact on the microstructure of CADI. 4. Adding water to the salt-bath furnace plays an effective role in the formation of ausferrite structure thus influencing mechanical properties

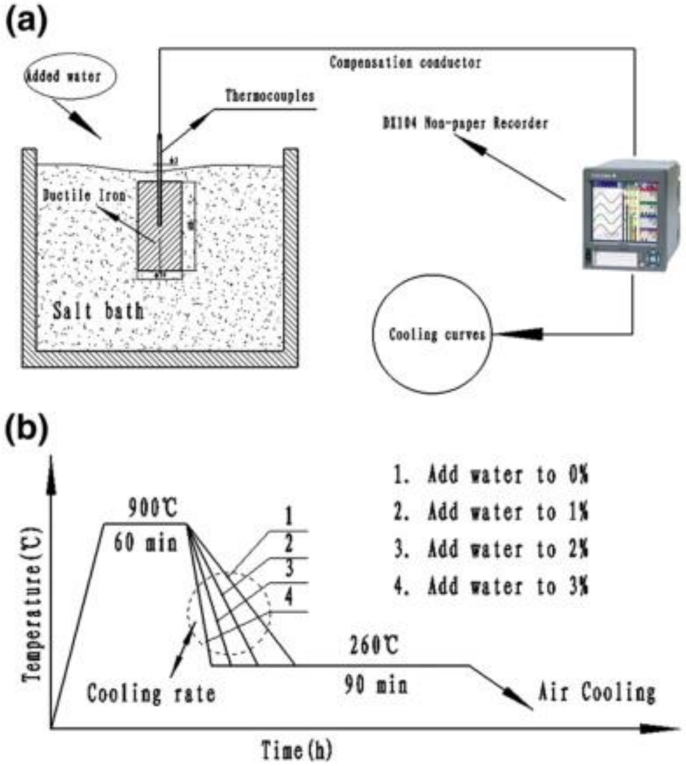


Fig 2.2 Schematic description of the salt bath while obtaining the different cooling rates. (a) Schematic description of the designed salt bath cooling ability. (b) Schematic description of austempering

Baer, W et. al.; [8] the appearance of chunky graphite in SGI is controlled by numerous, frequently interacting metallurgical factors. The chemical composition, solidification rate and nucleation have been identified as major influence factors. Developing quantitative rules to prevent chunky graphite has proved to be complex, and their practical impact has been limited due to narrow validity windows. It is established that the avoidance of chunky graphite in heavy sections cannot yet be rated a hundred percent process safe. Facing partly controversial results and the big scatter of literature data, no specific numbers of recommended chemical element contents, temperatures, etc., can be emphasized in this overview. Nevertheless, a reference line for preventive actions in terms of general metallurgical and process measures could be drawn to avoid chunky graphite in heavy-sectioned ferritic SGI castings. Among others, the most relevant measures reported to be effective against chunky graphite formation are increase in cooling rate, reduction in silicon content, control of trace elements and addition of specific alloying elements.

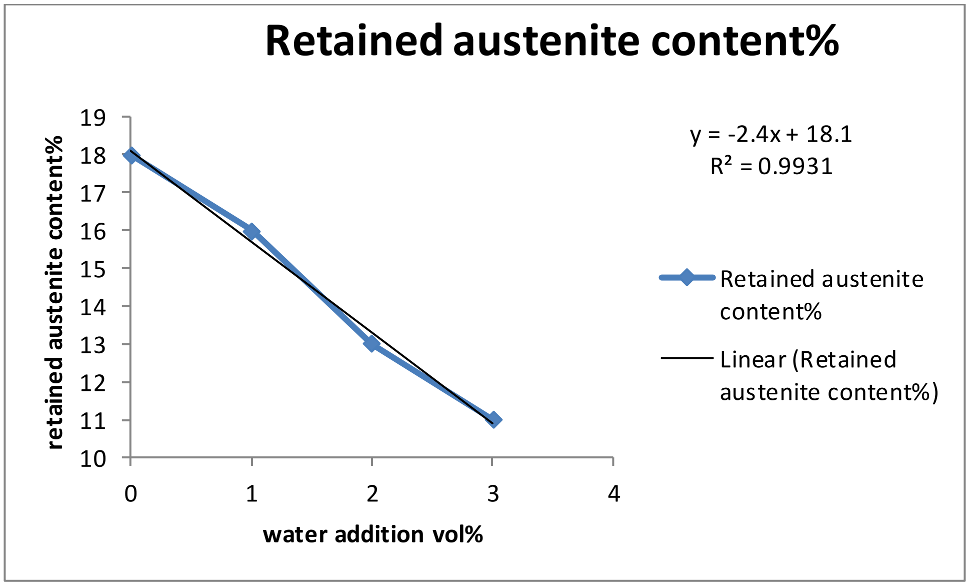


Fig2.3 Relationships for the retained austenite content with different amounts of water added.

Ferro, P., Lazzarin, P et. al.; [9] Fatigue tests and metallographic investigations were carried out on EN-GJS-400 ductile cast iron in order to evaluate the influence of CHG on fatigue resistance of this material. Statistical analysis of fatigue data was done both on the set of specimens containing chunky graphite and on the set of specimens without this defect. Finally, a further statistical analysis was obtained by using together all the cast iron samples. Metallographic investigations were carried out in order to correlate the fatigue behavior of the material under investigation with its microstructure. The main results are summarized as follows: CHG reduces significantly both the ultimate tensile stress and the elongation to fracture; but it does not influence the yield stress of the cast iron, if compared to specimens containing only nodular graphite.

Jayashree, M. S. G. D. M. V et.al.;[10] For microstructure analysis of SGI we computed quality parameters such as nodularity, nodule size and nodule count using the image processing algorithms like segmentation using global thresholding, boundary detection and classified for nodule size using artificial neural network. The results obtained from image processing method implemented for the analysis are found to be very close to the existing manual reports, thus proving the suitability of image processing algorithm for automation of microstructure analysis of SGI and report generation.

Pullan, T. T et. al.; [11] from the results obtained it can be concluded that to minimize the number of experiments to achieve the targeted mechanical properties in SGI casting, it is important to find the optimal chemical composition. The mechanical properties of ductile iron are controlled primarily by their matrix structure. Therefore, modification in the amount or distribution of matrix phases or microstructures can modify mechanical properties. The matrices of as-cast ductile irons are determined by cooling rate, composition, inoculation, pouring temperature, addition of rare earth elements and the content of pig iron in the charge. Properties of spheroidal graphite cast iron can be enhanced or altered according to service condition/application requirement. Earlier limitations on the usage of ductile iron due to limited knowledge of property enhancement processes can now be overcome by various heat treatment operations. In this research a study was performed to understand the effect of the heat operations tempering and austempering to transform the brittle behaviour to ductile behaviour which make SGI viable in various applications.

Serrallach, J., Lacaze et. al.; [12] the statistical analysis performed in this work allows mechanical properties of a specific alloy to be predicted as a function of the square root of the cooling rate (Vr), structural features (NA, f and fother) and the alloy's composition. As expected, an increase in the ferrite fraction decreases LE, UTS and D, and increases slightly rupture elongation. The most noticeable effect is that of the cooling rate which dramatically affects tensile and yield strengths as well as hardness.

Orulova, jeke & Olnniwo et. al.; [13] this study investigated the effect of magnesium and calcium as spheroidizers on the graphite microstructure in cast iron. The cast iron samples were melted in an induction furnace with charge of known composition and, magnesium and calcium of known percentages were added as spheroidizers to the molten metal in the mould during the casting process. From the microstructure of the as- cast specimens it was observed that the use of 100% Mg and a combined addition of 60% and 40%Ca as spheroidizers produced graphite spheroids instead of graphite flakes in the cast iron microstructure. The use of 100% Ca addition resulted in the production of graphite flakes in the specimen microstructure. The use of 80% Mg and 20% Ca resulted in the production of a chunky, stubby graphite microstructure, while the additions of 50% Mg and 50% Ca, 40%Mg and 60% Ca, and 20% Mg and 80% Ca resulted in the microstructure having a flaky graphite microstructure.

Eljack Babiker Eljack et. al.; [14] the type of foundries used in the Sudan are of two types, a captive type which produces castings that are further used in products manufactured by the same organization as in the case of Yarmok Industrial Complex. The second type is a jobbing foundry which produces castings as per orders. No mass production foundry type which can contribute to the public market is noticed. Most of the ongoing activities produce parts for maintenance works only.

Opportunities to reduce labour and energy and make other improvements must be pursued. Lean manufacturing and other concepts to improve operating efficiencies need to be pursued as do activity-based cost accounting approaches. Revolutionary technologies and process changes also should be investigated to achieve metal casting without use of tooling. The industry should investigate the application and blending of shop floor layout, computer numerical control, and scheduling technologies to radically change the nature of production in the sense of inventory levels, and delivery performance in metal casting plants.

Peng, Y. C., Jin, H. J et. al.; [15] Different cooling rates of salt-bath furnace were obtained by adding different water contents, which affects the microstructure and mechanical properties of CADI. It was found that the higher the water volume added to the salt bath, the higher the hardness of CADI. The highest hardness of the sample was obtained when the water content is approximately 3%. However, the impact toughness decreased gradually as the water increased. 3. The percentage content of retained austenite was altered by different cooling rates, and the cooling rate had a great impact on the microstructure of CADI.

Ferro, P., Lazzarin, P et. al.; [16] Fatigue tests and metallographic investigations were carried out on EN-GJS-400 ductile cast iron in order to evaluate the influence of CHG on fatigue resistance of this material. Statistical analysis of fatigue data was done both on the set of specimens containing chunky graphite and on the set of specimens without this defect. Finally, a further statistical analysis was obtained by using together all the cast iron samples. Metallographic investigations were carried out in order to correlate the fatigue behavior of the material under investigation with its microstructure. The main results are summarized as follows: CHG reduces significantly both the ultimate tensile stress and the elongation to fracture

Oluwole, Leke & Olorunniwo et. al.; [17] this study investigated the effect of magnesium and calcium as spheroidizers on the graphite microstructure in cast iron. The cast iron samples were melted in an induction furnace with charge of known composition and, magnesium and calcium of known percentages were added as spheroidizers to the molten metal in the mould during the casting process. From the microstructure of the as- cast specimens it was observed that the use of 100% Mg and a combined addition of 60% and 40%Ca as spheroidizers produced graphite spheroids instead of graphite flakes in the cast iron microstructure. The use of 100% Ca addition resulted in the production of graphite flakes in the specimen microstructure. The use of 80% Mg and 20% Ca resulted in the production of a chunky, stubby graphite microstructure, while the additions of 50% Mg and 50% Ca, 40%Mg and 60% Ca, and 20% Mg and 80% Ca resulted in the microstructure having a flaky graphite microstructure. On the strength of the results obtained from this research

Jayashree, M. S. G. D. M. V et.al.;[18] The use of magnesium as a spheroidzing agent produces spheroidal graphite cast iron having microscopic nodular graphite grains. These nodules have a minimum effect on the mechanical properties of the cast iron. The mechanical properties are mainly determined by the type of matrix structure and this imparts the favorable physical properties of cast iron (low melting point, good fluidity and castability), with the engineering advantages of steel (high strength, toughness, ductility, hot workability and hardenability). The use of calcium as a spheroidzing agent produces grey flake cast iron. The mechanical properties of the cast iron produced are influenced by the graphite flakes. The use of a combined addition of 60% Mg and 40% Ca as spheroidzing agent in an in- mould addition technique produces spheroidal graphite cast iron. This combined addition reduces the amount of Mg alloy used in the spheroidization process thereby reducing cost of production. The small shape of the nodule produced as shown in plate 4 also increases the nodularity of the cast iron. The use of other varying combined addition produces graphite flakes in the cast iron microstructure.

Imre KISS; Sorin RATIU; et. al.; [19] the technical conditions, which are imposed to the cast iron rolls in the exploitation period, are very different and often contradictory. The obtaining of various physical and mechanical properties in the different points of the same foundry product meets difficult technological problems in the industrial condition. This supposes us to know many technological factors, which lead to this deformation equipment

Mohammadreza Zamani et. al.; [20] two systems of Al-Si based casting alloys were studied in this thesis; Al-12 Si (EN AC-44300) and Al-Si-Cu-Mg (EN AC-46000). The effect of the casting defects (in particular porosity) on tensile properties and failure characteristic of EN AC-44300 alloy cast by high pressure die casting and gradient solidification technique was studied. The effect of cooling rate refinement and Sr-modification on porosity formation, microstructure and mechanical properties of EN AC-46000 alloy were investigated. Different approaches were examined in order to assess the level of Sr modification and find the optimum content of modification agent. The microstructural evolution and deformation behaviour of EN AC-46000 alloy comprising two distinctive coarseness of microstructure in the temperature range of room to 500 °C were studied. A physically based model was adapted and improved in order to describe flow stress curves of the alloy cast under different conditions.

Vyas, S., Jani et. al.; [21] we move forward to testing these specimen which include tensile, hardness, spectro & micro tests. After getting the various result we try to put various analysis for optimum results. After analysing Tensile & Hardness Result we show the same pattern for the various inoculant materials.

Table 2.3: Tensile & Hardness Result [13]

	Sr based	La based	Ca-ba based
Tensile	Low	Moderate	High
Hardness	Low	Moderate	High
Elongation	High	Moderate	Low

So by this result we found Ca-Ba type of inoculant use for the high tensile & hardness and Sr based inoculant use for the high ductility. But when we compare this to the standard all three value is going high. In this experiments we select two methods for inoculation treatment ex Pre inoculation & Post Inoculation Method. By the result we found post inoculation method is highly beneficial when we compare with another one.

Table 2.4: pre inoculation and post inoculation result [13]

Sr. no	Pre Inoculation	Post Inoculation
Tensile	Low	High
Hardness	low	High

2.2 SUMMARY OF LITERATURE REVIEW

From the above literature review conclude Most of the research paper concluded that Nodularity is Dependent on Magnesium Treatment If Mg treatment is improper the nodularity is lost in microstructure As Nodularity increase mechanical property also increase and other parameter soaking time which is considerable parameter for hardness and microstructure from above research paper conclude that the hardness and microstructure is depends on soaking time the effect of soaking time on microstructure and hardness of material 400/15 is to be carried out further stages so the effect of alloying element and soaking time on the microstructure and hardness by considering nodularity of microstructure and hardness in BHN is to be carried out.

TABLE 2.5: Relationship Between Alloying Elements and Its Impact On Results from Literature Review

INPUT PERAMETER	OUT PUT RESULT
SILICON	As the Si in the ductile iron matrix provides the ferritic matrix with the pearlitic one.
COPPER	It is a strong pearlite promoter. It increases the proof stress with also the tensile strength and hardness with no embrittlement in matrix.
Nickel	As it helps in increasing the U.T.S without affecting the impact Values.

2.3 Research gap

From various literature survey efforts to identify in some application nodularity is major parameter product quality is checked based on microstructure particularly on nodularity surface roughness and weight so some time it is difficult to maintain nodularity so here problem is to identify relationship between alloying element and soaking time on microstructure and hardness of sgi casting 400/15 so after studying the existing manufacturing process of product check the alloying contain and then its effect on microstructure and hardness and socking time effect on microstructure particularly nodularity and hardness.

CHAPTER – 3

METHODOLOGY

The showcased below are the step followed during the entire project study in company:

1. Analysis of the existing results of the nodularity by its percentage.
2. Analysis of the existing alloying elements which are added to the furnace.
3. Experiment the pilot value for chilled piece which are of grade 500/7.
4. Perform the experiments respectively using the selected values of input parameters.
5. Inspection and testing of the experimental samples for microstructure and hardness testing of the casting piece
6. Perform experiments of solidification by different time intervals.
7. Optimize of the input parameters and compute the values of output parameters for the same for getting the better result.
8. After that analysis of the sample and conclude the result to minimize the heat treatment cycle time by 1 hr.
9. Compare and validate results respectively in MINITAB software.
10. Generate the equation between nodularity

The flow chart of the entire work done during the entire Dissertation project study respectively.

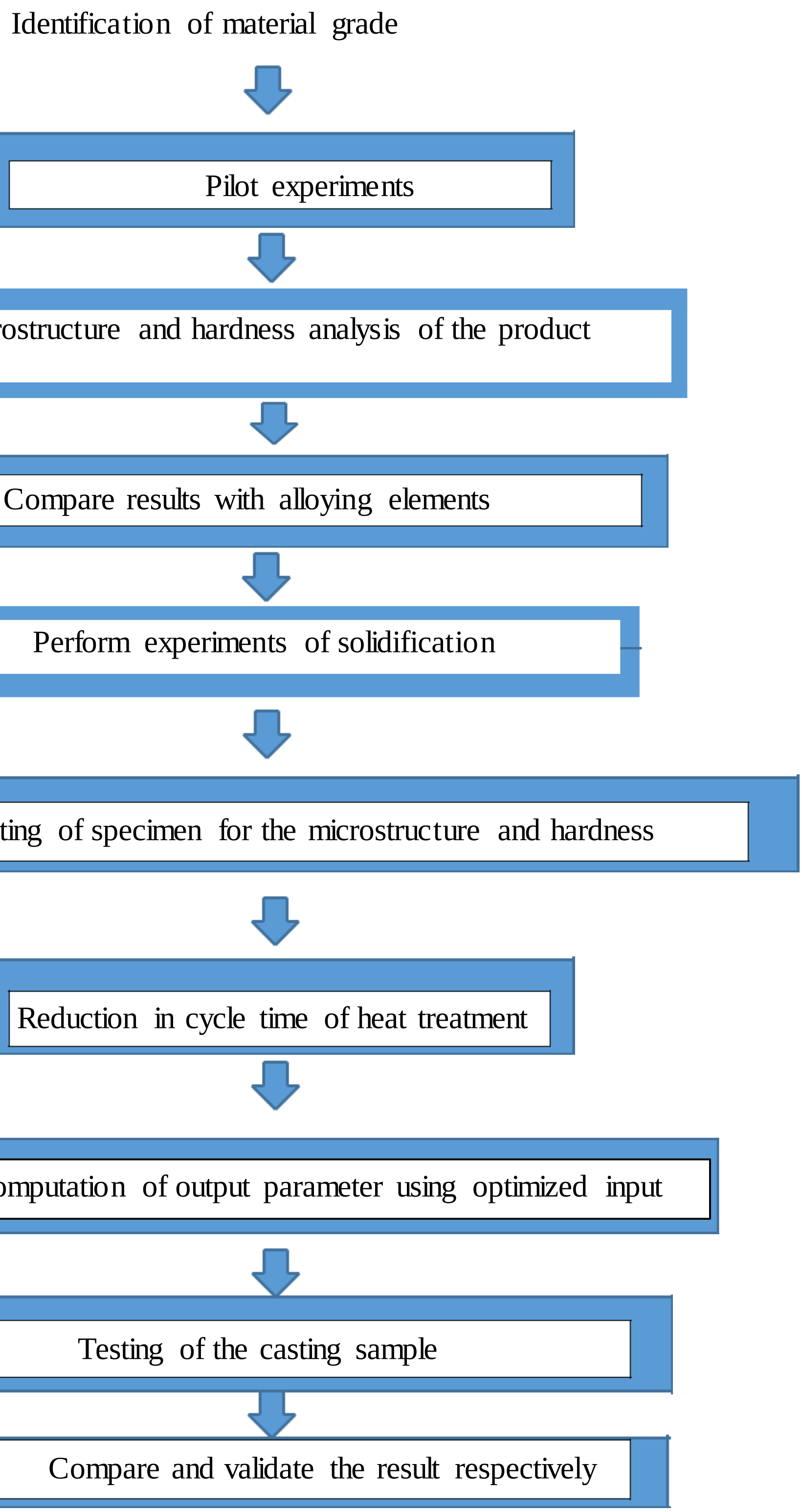


Fig 3.1-Flow chart for proposed work

3.2 Identification of Plate Material:

The identification of the casting cap material SGI 400/15 was important in order to know the chemical composition and mechanical properties of the base material respectively. The certificate or test report given below accordingly. The test was done by UNITECH LABORATORIES SERVICE at Gondal Road, Rajkot. The Material is meeting the requirements of chemical composition of SGI 400/15 Material. The fig 3.2 shows the material the material test report for SGI 400/15 material.

Table3.1 spectrographic result [Appendix D]

Elements	**Results**
% Carbon	3.630
% Silicon	1.540
% Manganese	0.238
% Phosphorus	0.014
%Sulphur	0.030
% Chromium	0.018
% Molybdenum	<0.010
% Nickel	0.011
% Copper	0.008
% Magnesium	<0.005

This report shows the alloying element content in the product which is already in use so we can estimate the addition of the alloying element addition in the furnace as per the requirement.

From the report we can also estimate the raw material for the product development as per these report criteria we will check the raw material chemical report and compare with this report so as per the standard we can add the alloying elements in the furnace.

3.3 Pilot testing:

The pilot testing of casting cap microstructure and hardness testing is done to identify the alloying elements effect on nodularity.
The experiment having different nodularity 90% 85% 80% 75% 70% respectively is tested and its alloying element list is given below.

Table 3.2: The Alloying Elements and its Nodularity [Appendix D]

Magnesium	Manganese	Sulfur	Silicon	Nodularity
1.4	0.197	0.0127	2.66	90%
1.9	0.209	0.0082	2.38	85%
1.9	0.395	0.0058	2.44	80%
1.9	0.209	0.0164	2.37	75%
1.4	0.230	0.0076	1.52	70%

3.4 ARPA 450 SJS Press:

the below 3.2 fig shows the moulding press which is used to made the mould.

Fig3.2: Mould making press

The above figure3.2 shows the press which is used to make the mould very tight to decrease the porosity and increase the hardness of the mould. This press is made by SSEC, Coimbatore. With the capacity to produce mould set of 35 with core and 45 without core.
With automated simultaneous jolt squeeze moulding machine-ARPA 450 press controlled with PLC, Capacity: 450 Kg, Production: 35-45 moulds per hour

3.5 Mould and Pattern making:

The making of mould by using mould box in fig 3.3 making of sand in fig 3.4 and the mould making.

Fig3.3 Mould **Fig3.4 Muller**

In in fig 3.3 the moulding box of mild steel is shown which is used to make the mould by using press which is fitted on the press and then the mould sand is pressed in the mould box by press. The mould is a size of 1200 mm x 2500 mm and its weight is 70 kg which is made up of mild steel.
S11 series roller type sand mill machine adopts the spring pressure technology and works inside and outside the scraper on the sand. Through stirring and rotating grinding wheel rolled up sand objective. Sand mill machine is a perfect sand mixing machine and widely used in medium and small foundry factory.
Application: S11 series roller type sand mill simple structure, reliable running, it is suitable for mixing moist molding sand, self-hardening sand, as well as water glass sand.

3.6 Pouring:

This is the pouring of the molten metal in mould cavity.it is done manually by the worker in this the mould is prepared and arranged in the line then the liquid metal from the furnace is taken in the small bucket by the worker and poured in the mould manually.

From 100 kg capacity of furnace there is a 6 mould can be poured. As shown in fig 3.6 there are two workers which is pouring the metal and the other one is removing the impurity which is need to be removed to reduce the rejection of the casting.

Fig 3.5 After pouring of molten metal in mould cavity

Fig3.6 pouring of molten metal in mould cavity

3.7 Introduction of material SGI 400/15:

- The nodular or Spheroidal graphite cast iron is also called ductile cast iron or high strength cast iron.
- It has high fluidity, castability, tensile strength, toughness, wear resistance, pressure tightness, weldability and machinability.

- It is generally used for castings requiring shock and impact resistance along with good machinability, such as hydraulic cylinders, cylinder heads, rolls for rolling mill and centrifugally cast products.

3.8 Chemical composition of SGI 400/15:

Here is the chemical composition specified by the manufacturer as per the standard and then in the second column there is the actual content of the material chemical report. So in first column we have the specified range of the chemical components so we can easily relate or compare the results of the spectrographic with the standard range.

Table3.3 Chemical compositions [15]

Element	Specified Content (%)	Actual Content (%)
Carbon (C)	3.40 – 3.85	3.8
Manganese (Mn)	0.10 to 0.30	0.21
Silicon (Si)	2.10 – 2.30	2.25
Sulfur (S)	0.020 Max	0.016
Phosphorous (P)	0.10Max	0.03
Magnesium (Mg)	0.07 MAX	0.002
Iron (Fe)	Remaining	Remaining

3.9 Current Heat Treatment Cycle:

1. First step of the heat treatment is to Preheating material up to 860 degrees centigrade for 8 hours (108 degrees per hour rise).
2. In second Step the material is stay as condition for Soaking period for 1 & ½ hours.
3. In third step the material should Cooling up to 650 degrees centigrade for2 & ½ hours in atmospheric.
4. So total cycle time is 12 hours to close and open the material.

3.10 Microstructure difference:

Here is the microstructure report of the final product which will use to calculate the nodularity of the product which is directly related with the elongation of the product.

In fig 3.7 it is shows that the 95 percentage nodularity from observation we can say that there are very small and fine black dots which is indicate the carbon in the nodule. and the small lines shows the graphite flacks which is shows the lower nodularity as the graphite flakes is less then nodularity is lower and as the nodule count increases the nodule count increases which is ultimately increases the nodularity of the product.

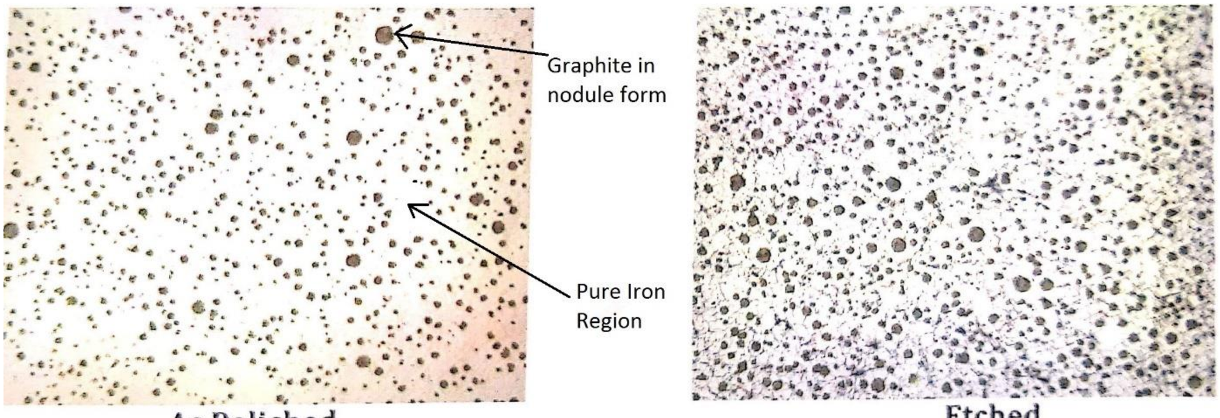
The most common etchants for cast irons is 2% Nital, however, a good resource for additional etchants can be found with the etchant database provided by PACE Technologies.

Cast Irons are difficult materials to prepare properly because the graphite nodules or the graphite flakes are easily fractured and pulled out during preparation. By minimizing the sectioning damage and starting with a modest grit size SiC paper, retaining these difficult particles can be accomplished.

in our experiments we used the Nital etchant which has composition of 96–98 mL ethanol

2–4 mL nitric acid (HNO3).

Most common etchant for iron, carbon, alloyed steels, and cast iron. Reveals alpha grain boundaries and constituents. The 2 or 4% solution is commonly used. Use by immersion of sample for up to 60 s.



As Polished

Etched

Fig 3.7This is the microstructure analysis report of nodularity with 95%

In fig 3.8 it is shows that there are almost half portion contains the graphite flacks and other half contains the carbon in nodule form which have 58 % nodularity.

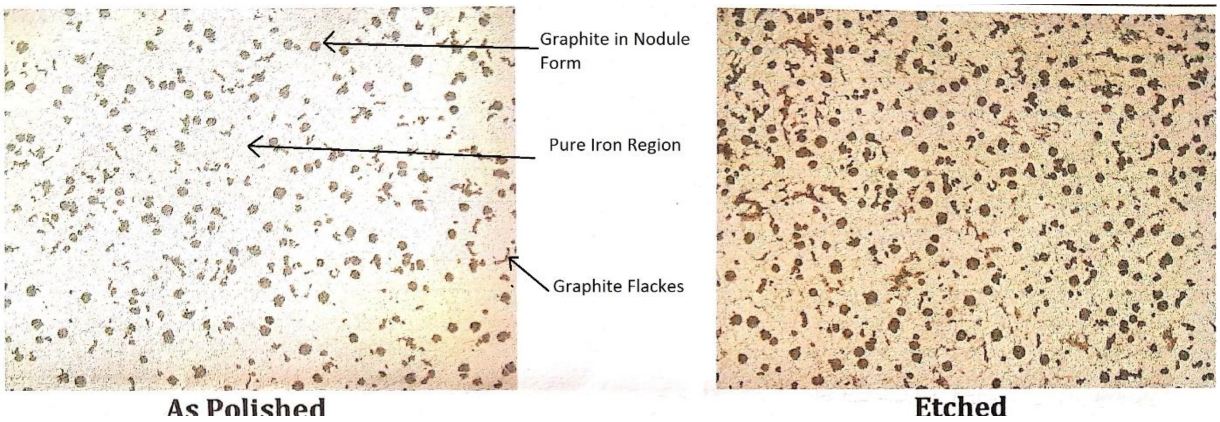


Fig 3.8This is the microstructure analysis report of nodularity with 58%

In fig 3.9 it is shows that there are large portion contains the graphite flacks and very lower part is containing the carbon in nodule form which have 32 % nodularity.

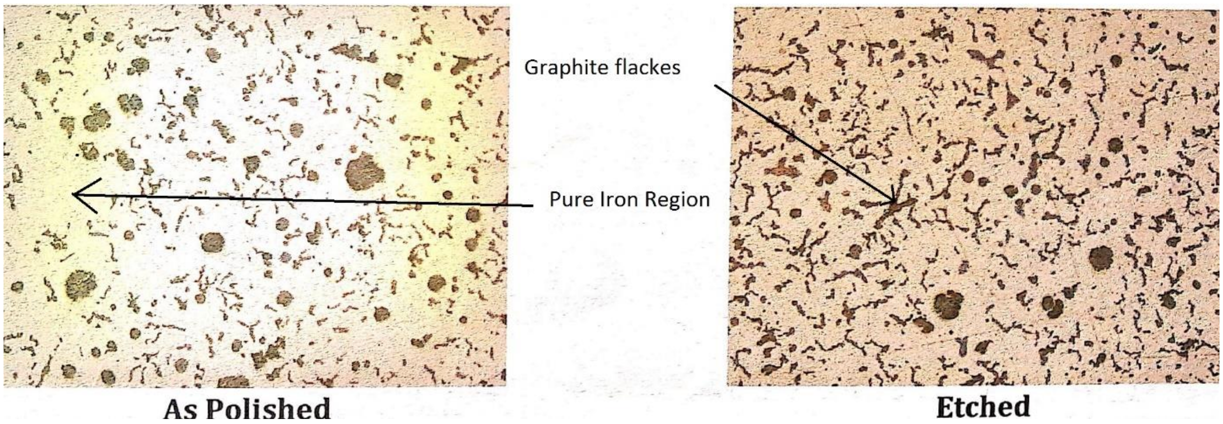


Fig 3.9This is the microstructure analysis report of nodularity with 32%

CHAPTER – 4

Design of Experiment

4.1. Experiments done by different hardness with nodularity:

In this experiment I have done microstructure analysis of nodularity and hardness as preference research paper it says that as the nodularity increases the hardness value decreases. [11]

In this experiments I have done the analysis of the nodularity count with hardness which is shows that as the nodularity decreases the hardness increases.

Table 4.1: Hardness vs. Nodularity

Nodularity(%)	Hardness (BHN)
92	121
91	156
89	180
78	188
66	197

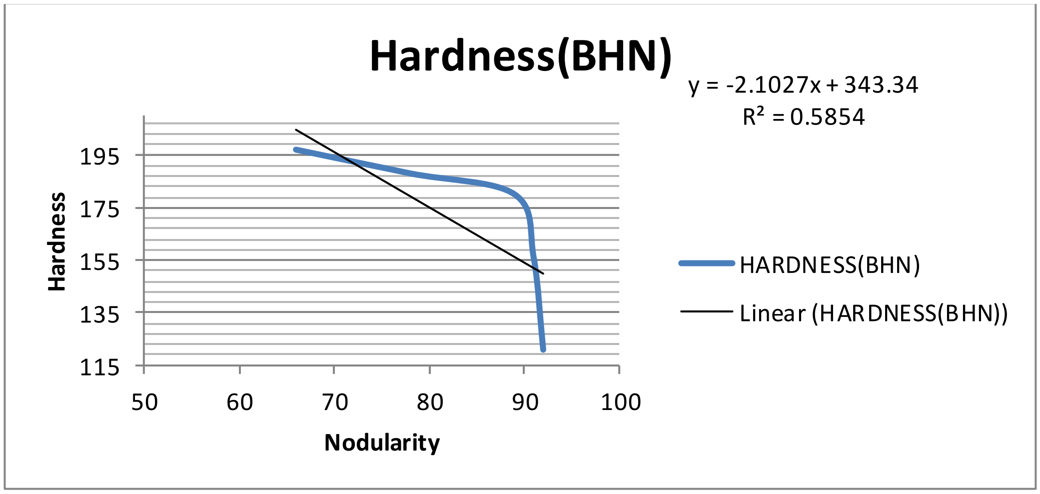


Fig 4.1 Relationship chart of nodularity with the hardness

4.2 Experiments performed by varying manganese percentage for possible change in nodularity:

In this experiment by decreasing manganese per gm. per kg of scrape the nodularity is increasing which is shown in below chart.

In as-cast irons, hardness, yield strength and tensile strength increase and tensile elongation is reduced, as manganese increases the pearlite fraction, see Figure 2. Ductile iron can become embrittled when the Mn level exceeds that required to achieve a fully pearlitic structure. [11]

The manganese contribution to a change of the graphite shape (in nodular graphite cast irons) has never been revealed. We made obvious the negative action of this element on the nodularization of graphite. Using SEM, we observe a significant change of the shape of the precipitated graphite (decrease of the shape coefficient values), depending on the cooling rate, the nature and the quantity of the nodularizing elements. The distribution of manganese and silicon in the metallic matrix and in the nodular graphite of cast irons with various amounts of manganese was studied using Casting Scanning X-ray Microprobe [14]

Table 4.2: Manganese vs. Nodularity

Mn(manganese)	Nodularity(%)
0.395	66%
0.345	70%
0.286	89%
0.229	92%
0.212	93%

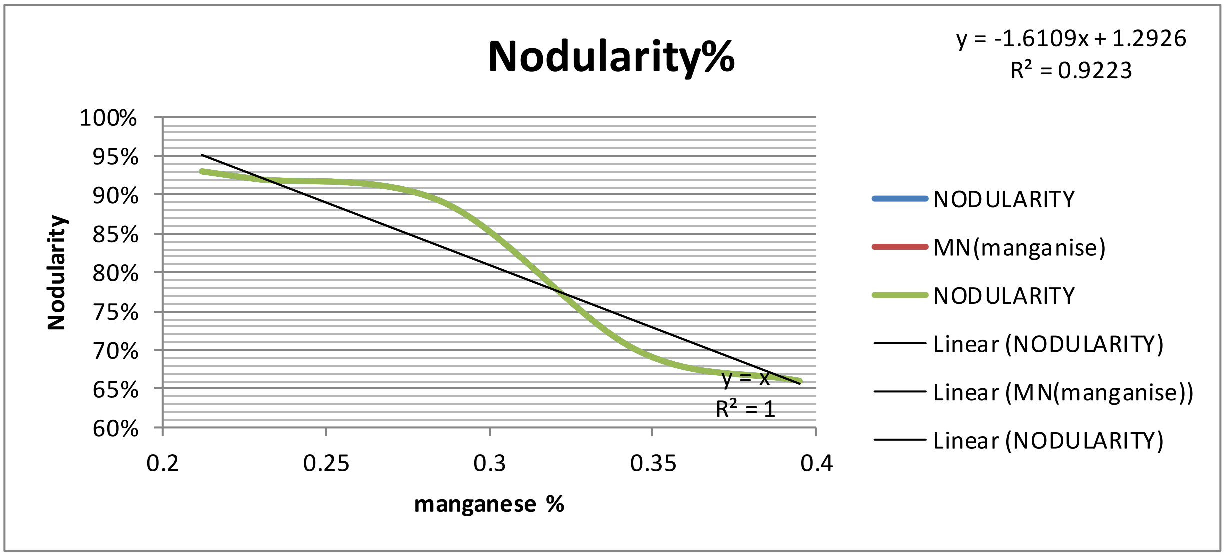


Fig 4.2 Relationship chart of Manganese with the Nodularity

4.3 Experiments performed by varying magnesium percentage for possible change in nodularity:

In this experiment by increasing magnesium in kg it is shows the nodularity is decreasing.

As we know, magnesium alloys with RE additions could enhance the mechanical properties drastically, especially at elevated temperatures. It is reported that Mg–Gd–Y–Zr alloys exhibit the higher specific strength at both room temperature and elevated temperatures.

Nucleation fades with time and castings should be poured within a time limit. Faded inoculation ca be restored or boosted with a little inoculant in the stream or in the mold, using any of several addition techniques.

Nodularity verification of each treatment batch is essential. The most positive verification is a quick microscopic examination of a specimen quickly polished and examined near the pouring floor. Ultrasonic instruments are also used to verify nodularity [15]

Table 4.3: Magnesium vs. Nodularity

Mg in g/kg of scrap	Nodularity(%)
1.4	92
1.45	89
1.5	88
1.9	80
1.95	78

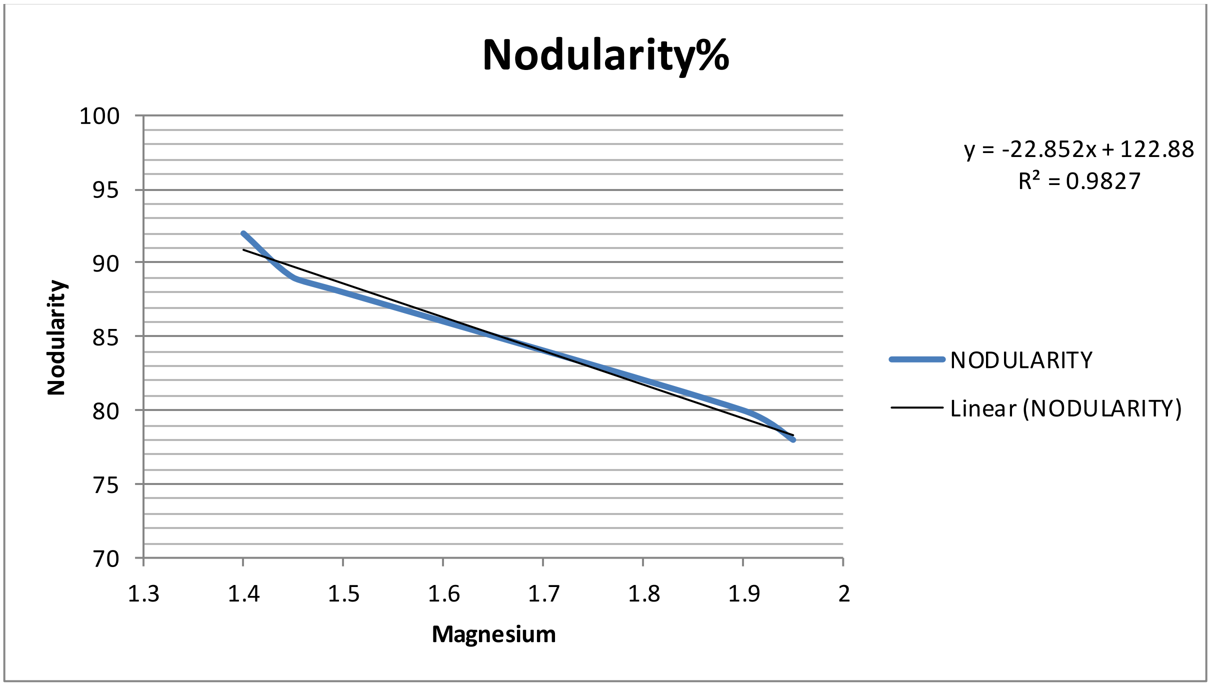


Fig 4.3 Relationship chart of Magnesium with the Nodularity

4.4 Experiments performed by varying Sulphur percentage for possible change in nodularity:

In this experiment by increasing sulfur content in the scrap the nodularity is decreasing.

Higher Sulphur levels call for increased additions of nodularizing alloy with consequent higher treatment costs and dangers of sulphite dross defects (Figure B). With these higher Sulphur levels there is an increased tendency for nodularity fade and of course problems in meeting required specifications. [16]

Table 4.4: Sulfur vs. Nodularity

Sulfur in g/kg of scrap	Nodularity(%)
4.4	92
4.9	89
5.2	86
5.8	66
6	60

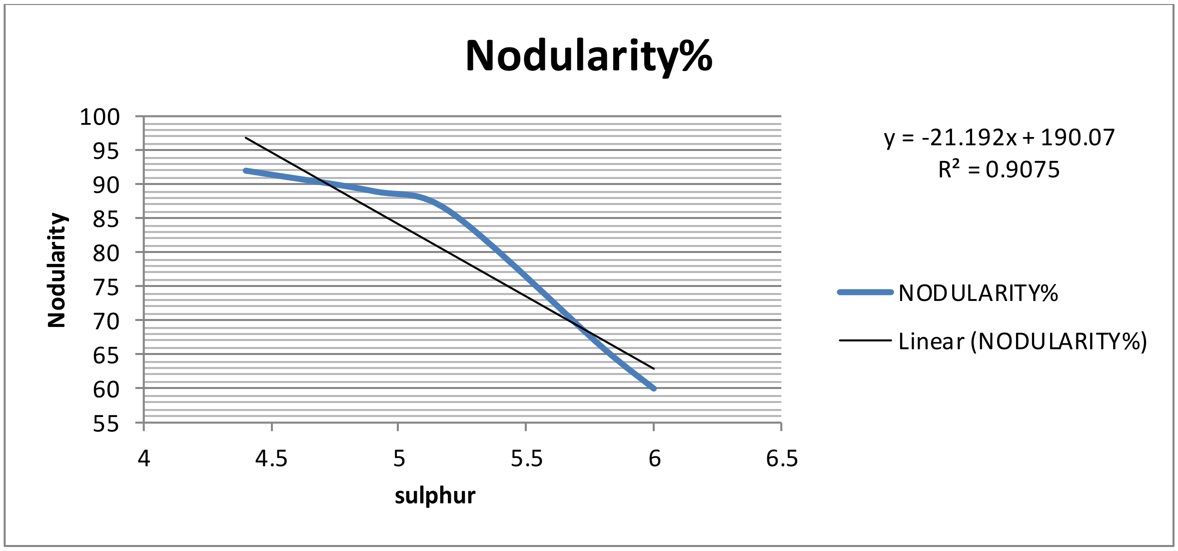


Fig 4.4 Relationship chart of sulfur with the Nodularity

4.5 Experiments performed by varying Silicon percentage for possible change in nodularity:

In this experiment we can conclude that as the silicon increasing the nodularity increasing.

The effects of silicon (Si) on the mechanical properties and fracture toughness of heavy-section ductile cast iron were investigated to develop material for spent-nuclear-fuel containers. Two castings with different Si contents of 1.78 wt. % and 2.74 wt. % were prepared. [12]

Four positions in the castings from the edge to the center, with different solidification cooling rates, were chosen for microstructure observation and mechanical properties' testing. Results show that the tensile strength, elongation, impact toughness and fracture toughness at different positions of the two castings decrease with the decrease in cooling rate. [14]

With an increase in Si content, the graphite morphology and the mechanical properties at the same position deteriorate. Decreasing cooling rate changes the impact fracture morphology from a mixed ductile-brittle fracture to a brittle fracture. The fracture morphology of fracture toughness is changed from ductile to brittle fracture. When the Si content exceeds 1.78 wt.%, the impact and fracture toughness fracture morphology transforms from ductile to brittle fracture. [15]

Table 4.5: Silicon vs. Nodularity

Si in g/kg of scrap	Nodularity(%)
2.15	92
2.3	89
2.37	78
2.4	75
2.44	66

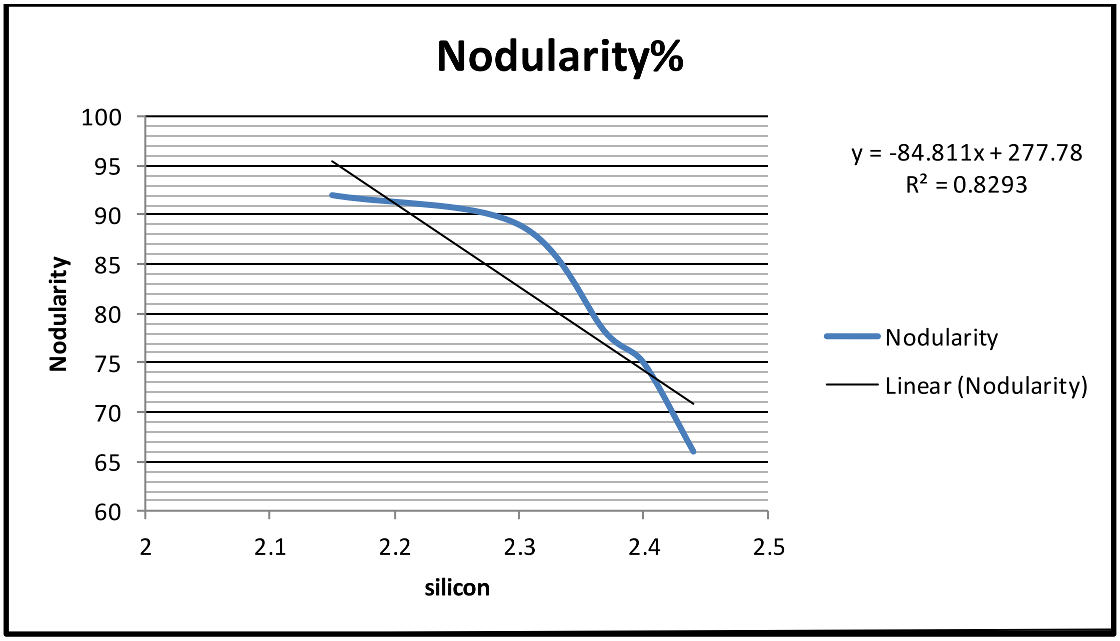


Fig 4.5 Relationship chart of silicon with the Nodularity

4.6 Experiments performed by varying pouring time for possible change in nodularity:

In this experiment we can conclude that as the pouring time increasing the nodularity decreasing.

The effect of holding time, thickness and annealing heat treatment on the microstructure and some mechanical properties of compacted graphite iron (CGI) are studied. Samples of CGI are produced in Helwan factory for casting by using GGG 70 as base metal in a medium frequency induction furnace. [15]

The mechanical properties (tensile strength, and hardness) of the as-cast and after heat treatment samples are determined and the microstructure of the samples is examined using optical microscope. The results show that the mechanical properties and microstructure of CGI depend on holding time, thickness and annealing heat treatment; it is found that increasing the holding time from 10 min to 17 min results in lowering the Mg content from 0.031% to 0.021% and as a result lower nodularity was obtained. [16]

Pouring temperature is measured by the chemical meter which is used to measures the carbon magnesium sulfur percentage in the furnace so we can add of remove some amount of unnecessary material or content which is extra. [17]

Lowering the thickness from 20 mm to 5 mm increases the tendency of dendritic structure as a result of increasing the cooling rate.

Table 4.6: Pouring time vs. Nodularity

Pouring time	Nodularity(%)
130	92%
150	89%
160	88%
170	78%
180	66%

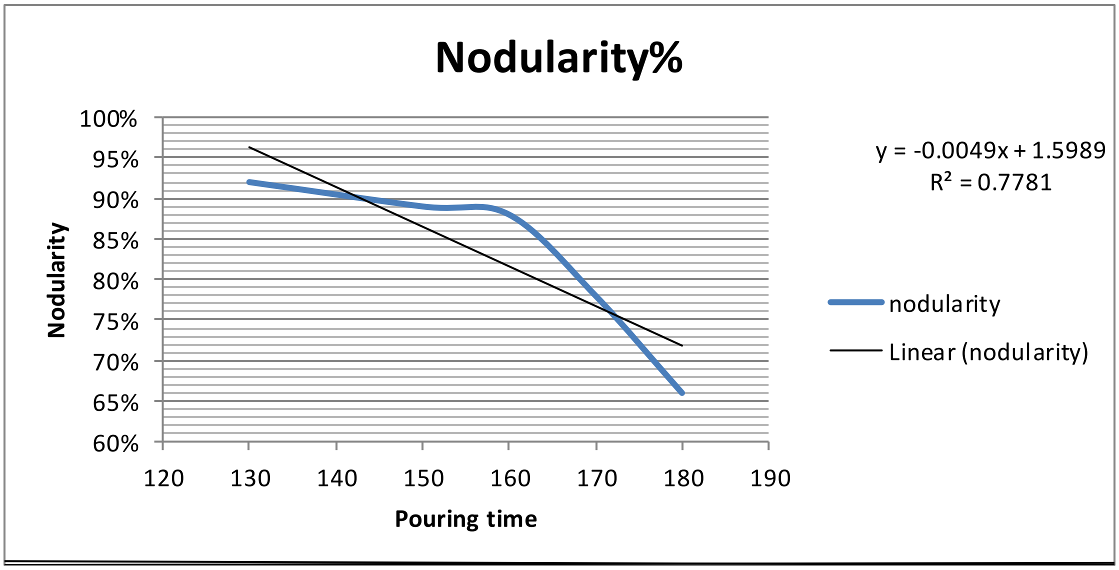


Fig 4.6 Relationship chart of pouring time with the Nodularity

4.7 Experiments performed by varying pouring temperature for possible change in nodularity:

In this experiment we can conclude that as the pouring temperature increasing the nodularity decreasing.

Ductile iron in the form of Y-blocks was produced by lost foam casting with different pouring temperatures, and the graphite morphology, matrix structure and mechanical properly were studied. Because of the serious burning loss of carbon and silicon elements with the pouring temperature of 1510°C, a lot of carbide in matrix formed. The nodularity and nodular level of ductile iron was decreased, caused by the low pouring temperature of 1410°C, which led to the decrease of tensile strength and elongation. The experiments indicate that the pouring temperature of 1460°C is proper. [18]

Table 4.7: Pouring temperature vs. Nodularity

Pouring Temperature ^{O}C	Nodularity(%)
1400	95
1450	93
1500	86
1550	85
1600	70

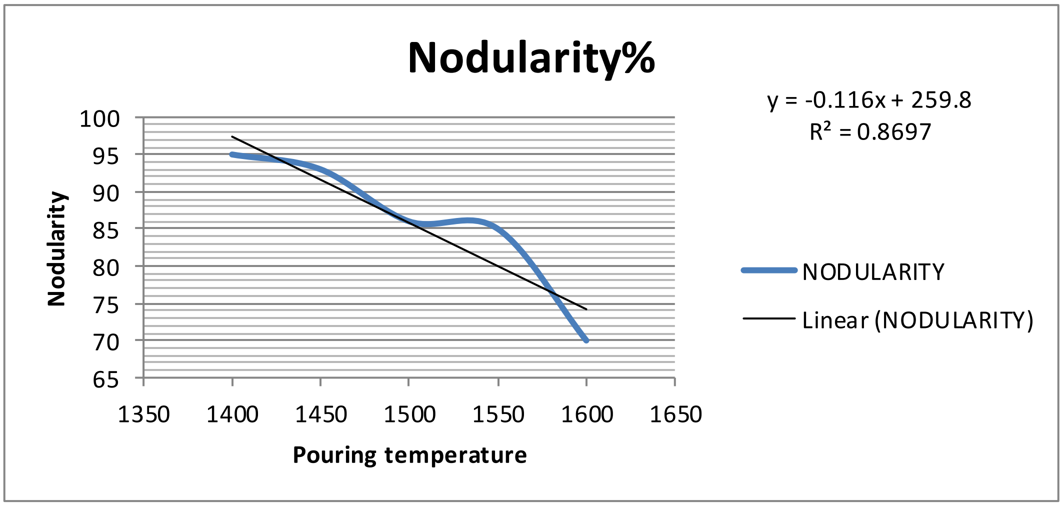


Fig 4.7 Relationship chart of pouring temperature with the Nodularity

4.8 Experiments performed by varying mould breaking time for possible change in nodularity:

In this experiment after pouring we will break the mould in different time intervals and observe the output of nodularity so by this experiment we can conclude that by increasing mould breaking time has no impact on nodularity but the hardness is decreasing so on this basis we can reduce the heat treatment time by the 1 hr.

The outstanding properties of ductile iron are due to a nodular or spheroidal form of precipitated graphite in the microstructure. This favorable nodular graphite shape is obtained by treating with Magnesium to retain residual Mg content within narrow control limits, then inoculating with ferrosilicon to nucleate that graphitization. [17]

Mg is a very volatile and reactive element and is difficult to control. Occasional “misses” are possible and likely.

Many alloying and treatment methods have been used to successfully introduce Mg with various levels of recovery. But, all treatment processes are subject to iron variables, alloy variables, and mechanical variables which must be understood and controlled. [18]

The second step of ductile iron treatment is post inoculation with foundry grade FeSi to nucleate and encourage graphite precipitation. Good inoculation prevents formation of undesirable carbides which are very detrimental to ductility and also encourages good graphite form, size and distribution. [19]

Table 4.8: Mould breaking time vs. Hardness

solidification time(min)	hardness(BHN)	Nodularity(%)
5	195	87
10	169	89
15	144	90
20	121	88

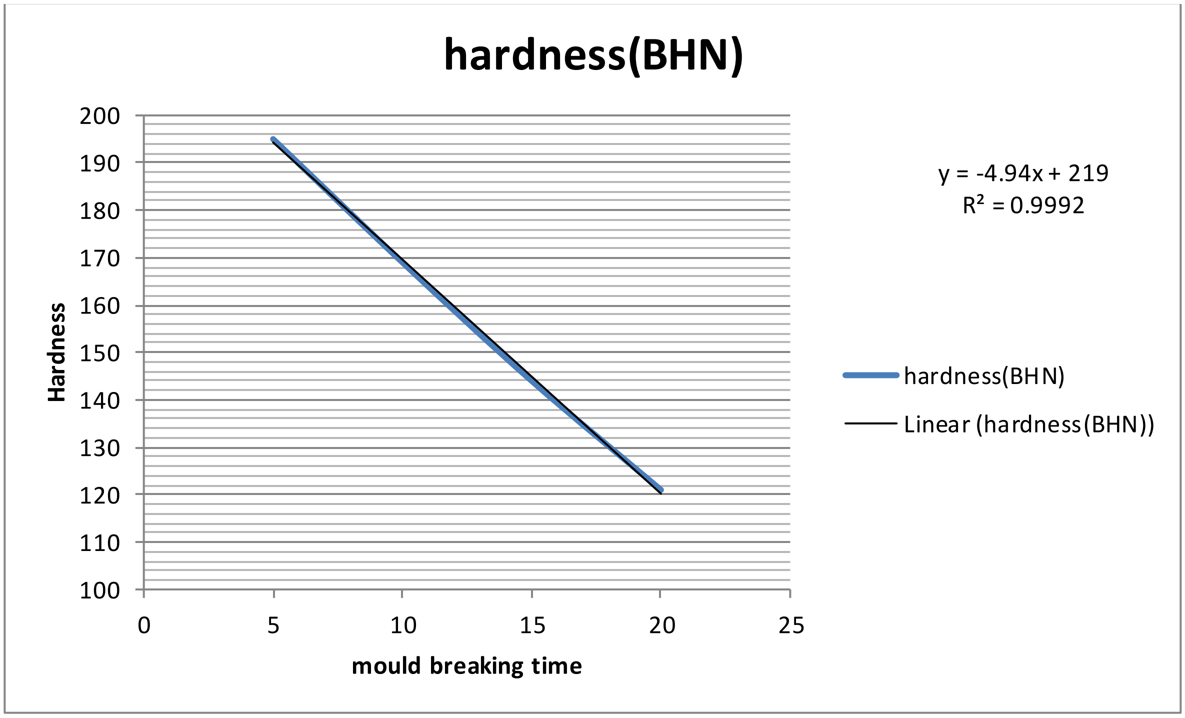


Fig 4.8 Relationship chart of mould breaking time with the hardness

4.9 Regression Analysis: nodularity versus mg, mn, s, si, mg*mn, mn*s, s*si, si*mg, mn*si, mg*s, mg*mn*s, mn*s*si, s*si*mg, mn*mg*s*si.:

In statistical modeling, regression analysis is a set of statistical processes for estimating the relationships between a dependent variable (often called the 'outcome variable') and one or more independent variables (often called 'predictors', 'covariates', or 'features'). The most common form of regression analysis is linear regression, in which a researcher finds the line (or a more complex linear combination) that most closely fits the data according to a specific mathematical criterion.

Regression Equation:

Here is the final regression equation which is used to estimate the nodularity by varying alloying elements.

Nodularity = -1.04 + 0.828 mg + 5.36 mn + 181 s + 0.405 si - 2.66 mg*mn -
791 mn*s - 21 s*si - 0.110 si*mg - 0.32 mn*si - 127 mg*s
+ 585 mg*mn*s + 71 mn*s*si + 22.3 s*si*mg - 99 mn*mg*s*si

Coefficients:

SE Coef shows the standard error is an estimate of the standard deviation of the coefficient, the amount it varies across cases. It can be thought of as a measure of the precision with which the regression coefficient is measured.

The t statistic is the coefficient divided by its standard error. The standard error is an estimate of the standard deviation of the coefficient, the amount it varies across cases. It can be thought of as a measure of the precision with which the regression coefficient is measured.

The p-value for each term tests the null hypothesis that the coefficient is equal to zero (no effect). A low p-value (< 0.05) indicates that you can reject the null hypothesis. Typically, you use the coefficient p-values to determine which terms to keep in the regression model.

VIF: In statistics, the variance inflation factor is the quotient of the variance in a model with multiple terms by the variance of a model with one term alone. It quantifies the severity of multi col linearity in an ordinary least squares regression analysis.

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	-1.04	1.02	-1.01	0.315	
Mg	0.828	0.424	1.95	0.055	1898.66
Mn	5.36	4.33	1.24	0.220	1263.26
S	181	280	0.65	0.520	267222.37
si	0.405	0.373	1.08	0.282	1471.82
mg*mn	-2.66	1.50	-1.77	0.082	1471.82
mn*s	-791	1309	-0.60	0.548	268286.75
s*si	-21	116	-0.18	0.860	268462.47
si*mg	-0.110	0.120	-0.92	0.362	1263.26
mn*si	-0.32	1.50	-0.22	0.830	1898.66
mg*s	-127	162	-0.78	0.436	268822.12
mg*mn*s	585	759	0.77	0.444	268462.47

mn*s*si	71	545	0.13	0.897	268822.12
s*si*mg	22.3	67.5	0.33	0.742	268286.75
mn*mg*s*si	-99	315	-0.31	0.754	267222.37

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.0178848	74.17%	68.69%	59.02%

R-sq.:

R^2 is the percentage of variation in the response that is explained by the model. It is calculated as 1 minus the ratio of the error sum of squares to the total sum of squares (which is the total variation in the model). R2 is just one measure of how well the model fits the data. Even when a model has a high R2, you should check the residual plots to verify that the model meets the model assumptions.

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	14	0.060625	0.004330	13.54	0.000
mg	1	0.001219	0.001219	3.81	0.055
mn	1	0.000491	0.000491	1.53	0.220
S	1	0.000134	0.000134	0.42	0.520
Si	1	0.000376	0.000376	1.18	0.282
mg*mn	1	0.001001	0.001001	3.13	0.082
mn*s	1	0.000117	0.000117	0.36	0.548
s*si	1	0.000010	0.000010	0.03	0.860
si*mg	1	0.000270	0.000270	0.84	0.362
mn*si	1	0.000015	0.000015	0.05	0.830
mg*s	1	0.000197	0.000197	0.62	0.436
mg*mn*s	1	0.000190	0.000190	0.59	0.444
mn*s*si	1	0.000005	0.000005	0.02	0.897
s*si*mg	1	0.000035	0.000035	0.11	0.742

mn*mg*s*si	1	0.000032	0.000032	0.10	0.754
Error	66	0.021111	0.000320		
Total	80	0.081736			

Fits and Diagnostics for Unusual Observations

Obs.	nodularity	Fit	Resid	Std Resid
4	0.86000	0.90887	-0.04887	-3.04 R
9	0.94000	0.89549	0.04451	2.53 R
24	0.94000	0.90235	0.03765	2.19 R
42	0.94000	0.91060	0.02940	2.24 R
52	0.91000	0.94113	-0.03113	-2.22 R
63	0.86000	0.89475	-0.03475	-2.02 R

R Large residual

A residual plot is a graph that is used to examine the goodness-of-fit in regression and ANOVA. Examining residual plots helps you determine whether the ordinary least squares assumptions are being met.

Histogram of residuals:

Use the histogram of residuals to determine whether the data are skewed or whether outliers exist in the data.

Normal probability plot of residuals:

Use the normal plot of residuals to verify the assumption that the residuals are normally distributed.

Residuals versus fits:

Use the residuals versus fits plot to verify the assumption that the residuals have a constant variance.

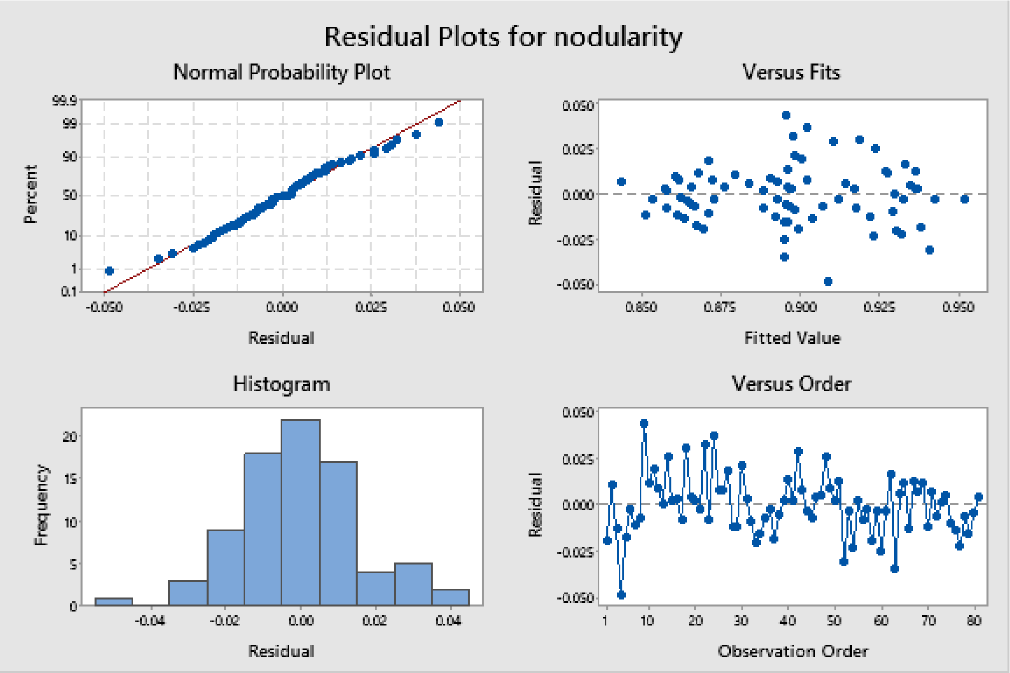


Fig 4.9 residual plots for nodularity

Residuals versus order of data:

Use the residuals versus order plot to verify the assumption that the residuals are Uncorrelated with each other.

4.10 Main Effects Plot for nodularity:

From the main effect plots we can conclude that as mg content should be more than 1.9% for the better nodularity as the mg content decreases from the 1.9% it shows that the nodularity will decrease.

From mn plot we can conclude that the mn content should be in the range of 0.20 to 0.23 for the better output of the nodularity.

From the s plot we can conclude that the Sulphur content should be in the range of 0.0050 to 0.0110 for the better result of the nodularity.

From the si plot we can conclude that as the silicon content increases the nodularity will shows increasing.

Now from all this regression analysis we can conclude that there is no individual effect of the alloying elements in the casting of 400/15 there are combine effect of the alloying elements which will produce the nodule count and then nodularity increases as the combine effect of the alloying elements

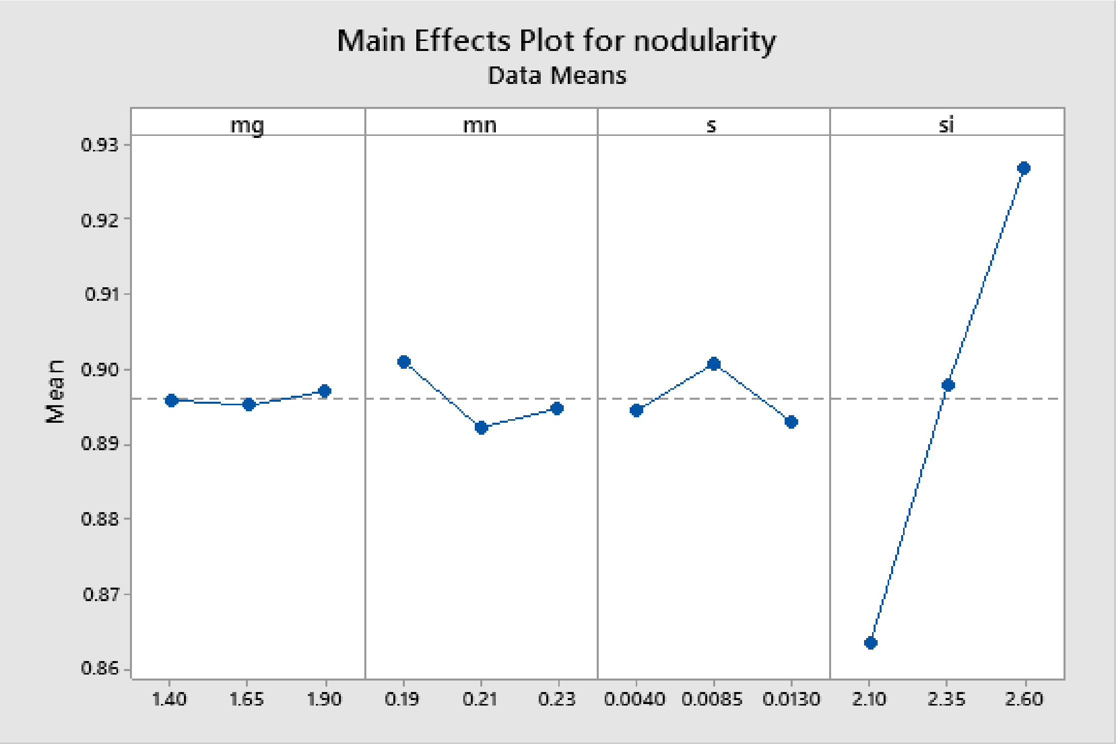


Fig 4.10 main effect plots for nodularity

CHAPTER 5

Result and Discussion

5.1 Introduction:

In order to resolve this problem, we have done trial experiments at the Kishor Casting Co. Rajkot. The results from the experiments are as below and some crucial points have been discussed from the experiments.

5.2 Results:

From the experiments we can conclude that as the nodularity increases the hardness decreasing and elongation increases so in our product the major requirement is that the material of the product should have high elongation capacity.

- From the experiment it can conclude that the alloying element has major impact on the nodularity.
- Like sulfur, silicon, manganese, magnesium, which we discussed above:
  - As the sulfur content per kg of scrap increases the nodularity decreasing.
  - As the silicon content percentage per kg of scrap increasing the nodularity decreasing also as the silicon percentage decreasing per kg of scrap below some limit also nodularity decreasing. So we can find the range of silicon should be between (2.0% to 2.6%).
  - As the manganese percentage per kg of scrap decreasing the nodularity increasing.
  - As the magnesium in magnesium treatment increasing the nodularity decreasing and also as decreasing magnesium also nodularity decreasing so magnesium in magnesium treatment also between 1.4 kg to 1.6 kg per 100 kg of induction capacity.

Table 5.1: Experimental Output

NO	mg	mn	s	si	Nodularity
1	1.4	0.21	0.0085	2.6	95.00%
2	1.4	0.19	0.0085	2.35	92.00%
3	1.4	0.19	0.013	2.6	95.00%
4	1.65	0.23	0.004	2.35	93.00%
5	1.9	0.19	0.0085	2.35	92.00%
6	1.65	0.19	0.0085	2.6	94.00%
7	1.4	0.23	0.013	2.6	90.00%
8	1.4	0.21	0.013	2.1	86.00%
9	1.65	0.19	0.013	2.6	92.00%
10	1.65	0.21	0.013	2.35	89.00%
11	1.4	0.21	0.0085	2.1	86.00%
12	1.65	0.21	0.0085	2.35	91.00%
13	1.9	0.23	0.013	2.35	90.00%
14	1.9	0.23	0.013	2.6	94.00%
15	1.65	0.19	0.0085	2.1	87.00%
16	1.4	0.19	0.0085	2.6	94.00%
17	1.65	0.23	0.0085	2.1	86.00%
18	1.9	0.23	0.0085	2.1	88.00%
19	1.9	0.23	0.0085	2.6	92.00%
20	1.9	0.19	0.013	2.6	95.00%
21	1.4	0.23	0.0085	2.35	90.00%
Average optimum result	1.62	0.21	0.01	2.39	91%

- From experiment we can also conclude that as nodularity is also depending on the pouring time and pouring temperature:
  - As the pouring time increasing the nodularity decreasing.
  - As the pouring temperature increases nodularity also decreasing.
- Now from experiment of mould breaking by breaking the mould in different time intervals it is not give the major effect on the nodularity but the hardness decreases as the mould breaking time is increases.

- so from the 81 experiments there are 21 results shown in table which is better results and from that we can find the optimum alloying element contain for better nodularity which is shown highlighted green portion.

5.3 Discussion:

- The focus of this research work is more weight on the industry's needs. The main goal of this research work is to minimize the existing part rejection ratio and increase company's profit.
- Hence, the research work for the reduction of rejection due to low nodularity in this product the nodularity should be more than 85% so if the nodularity will come below 85% it means whole lot rejected means it will directly loose company's profit. So we need to identify the affecting parameter on nodularity.
- So we need to optimize the alloying element content to get better result of nodularity.
- So by using MINITAB software we can conclude the results of nodularity.
- And we also need to decrease the heat treatment cycle time to save the cost.

Chapter 6

Conclusions & Future Scope

6.1 CONCLUSION:

- From the experiments and the MINITAB software analysis we can conclude that:

Table 6.1: Optimum Result

Alloying elements	Optimum range
manganese	210 to 290 gm. per kg of scrap
silicon	2.00 to 2.60 kg per kg of scrap
sulphur	4.00 to 5.20 gm. per kg of scrap
magnesium	1.4 to 1.6 kg per 100 kg of the furnace capacity
pouring temperature	1400˚C to 1450˚C
pouring time	170 sec for 100 kg of furnace capacity
mould breaking time	break after 15 min of pouring

- The alloying elements content should be in range as discussed below:
- Manganese should be in the range of 210 to 290 gram per kg of scrap.
- Silicon should be in range of 2.00 to 2.60 kg per kg of scrap.
- Sulfur should be in the range of 4.00 to 5.20 gram per kg of scrap.
- Magnesium which are used to convert the CI casting into the SGI casting should be in the range of 1.4 to 1.6 kg per 100 kg of the furnace capacity while doing magnesium treatment.
- So the selection of the alloying element in this range will be reduce the rejection of the lot and also increase the production rate which is beneficial to the company's profit.
-

- Also from the experiment of mould breaking in the different time intervals:
  - We can conclude that as the mould breaking time increases the nodularity has no much impact but the hardness decreases due to long duration of heat stay in the mould.
  - So due to hardness decreasing we can reduce the heat treatment time by 1 hr. which is increase the profit of the company.
- From the MINITAB software also we can conclude that the effect of alloying element is more in combination than individual.

6.2 FUTURE SCOPE:

- From doing this research work we can conclude the range of alloying elements and the mould breaking time in future we can do the experiments to increase the nodularity, decrease in hardness and increase in the elongation of the product by adding the elements during the pouring of the material in the mould which will also improve the nodularity and the elongation of the product which will ultimately decreases the heat treatment cycle time which is beneficial to the company's profit.
- Also there is various inoculation treatments are used to eliminate the heat treatment processes but it is costly than conventional method but it will save the time so in future there is area to work on cheap inoculation treatment cost which will be the lower than the conventional heat treatment processes.

CHAPTER 7

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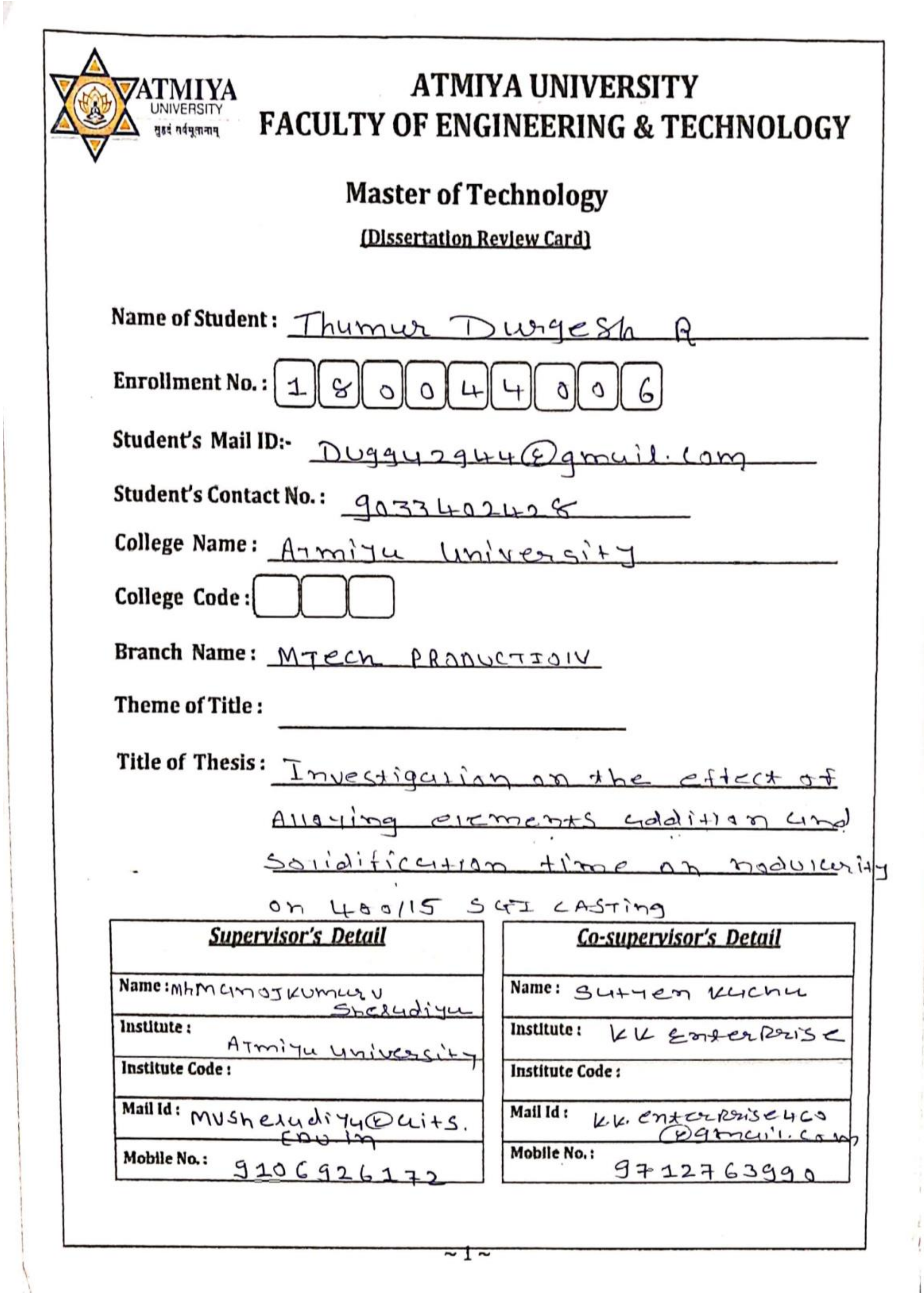
WEBSITES

[1] www.kkenterprise.com

Appendix A: Review Card



ATMIYA UNIVERSITY
FACULTY OF ENGINEERING & TECHNOLOGY

Master of Technology
(Dissertation Review Card)

Name of Student : Thumar Durgesh R

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College Name : Atmiya University

College Code : ☐☐☐

Branch Name : MTech PRODUCTION

Theme of Title :

Title of Thesis : Investigation on the effect of Alloying elements addition and solidification time on nodularity on 400/15 SGI CASTING

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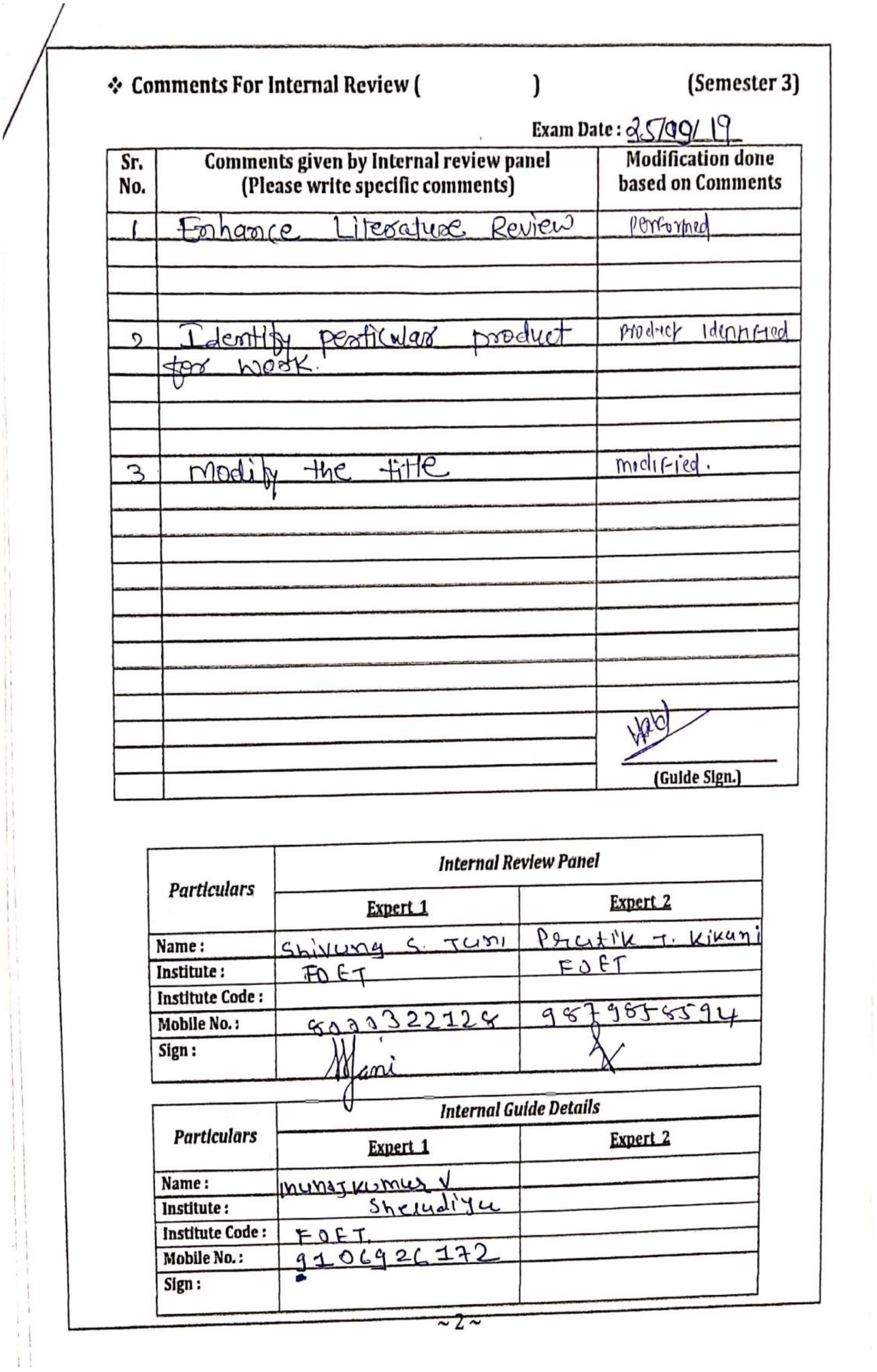

❖ **Comments For Internal Review (   )** **(Semester 3)**

Exam Date : 25/09/19

Sr. No.	**Comments given by Internal review panel (Please write specific comments)**	**Modification done based on Comments**
1	Enhance Literature Review	performed
2	Identify particular product for work.	product identified
3	modify the title	modified.

(Guide Sign.)

Particulars	**Internal Review Panel**	
	Expert 1	**Expert 2**
Name :	Shivang S. Jani	Pratik J. Kikani
Institute :	FOET	FOET
Institute Code :		
Mobile No. :	8000322128	9879858594
Sign :	Jani	

Particulars	**Internal Guide Details**	
	Expert 1	**Expert 2**
Name :	Manojkumar V Shekhadiya	
Institute :		
Institute Code :	FOET.	
Mobile No. :	9106926172	
Sign :		

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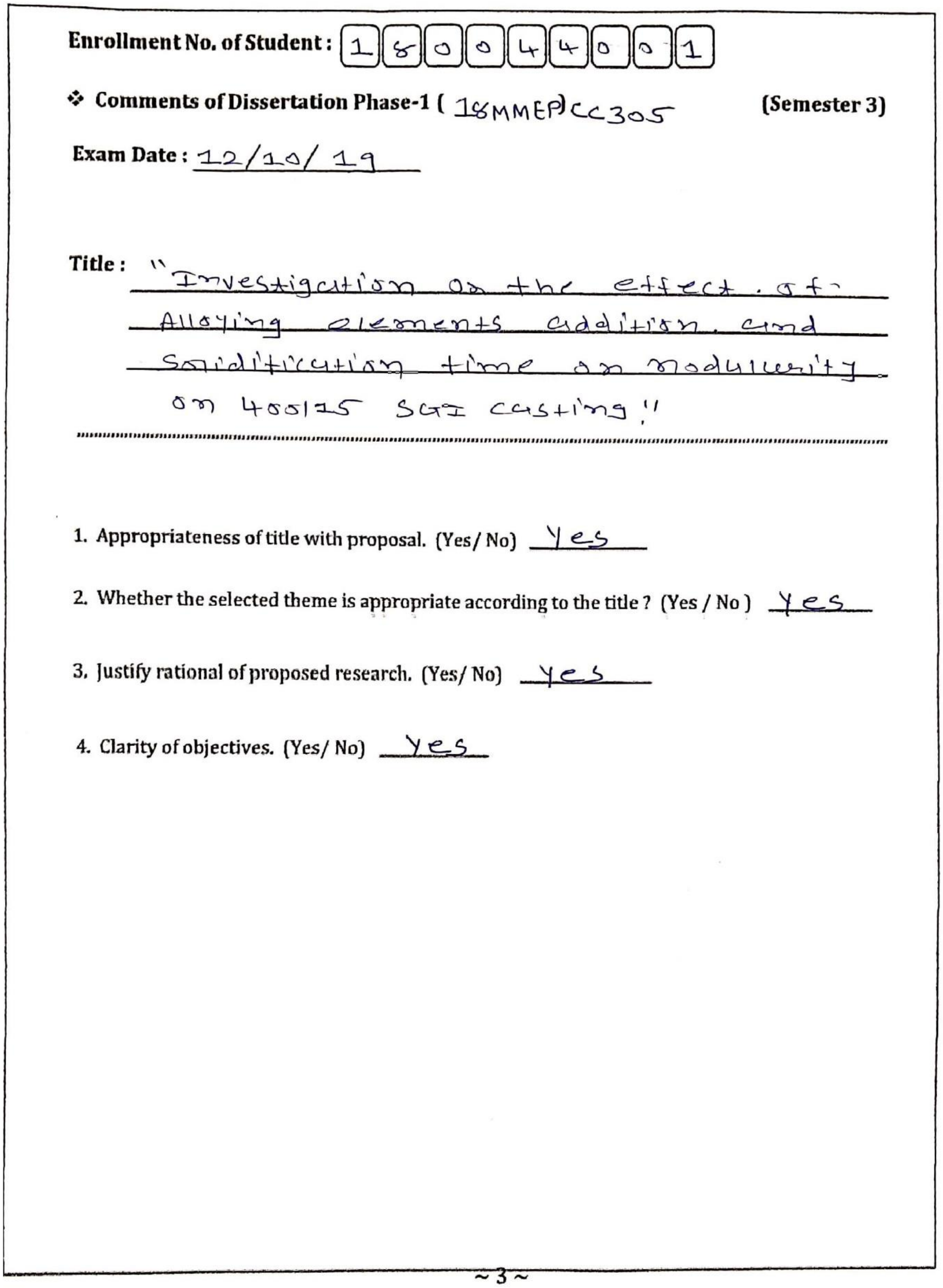
Appendix A: Review Card



Enrollment No. of Student : 1 8 0 0 4 4 0 0 1

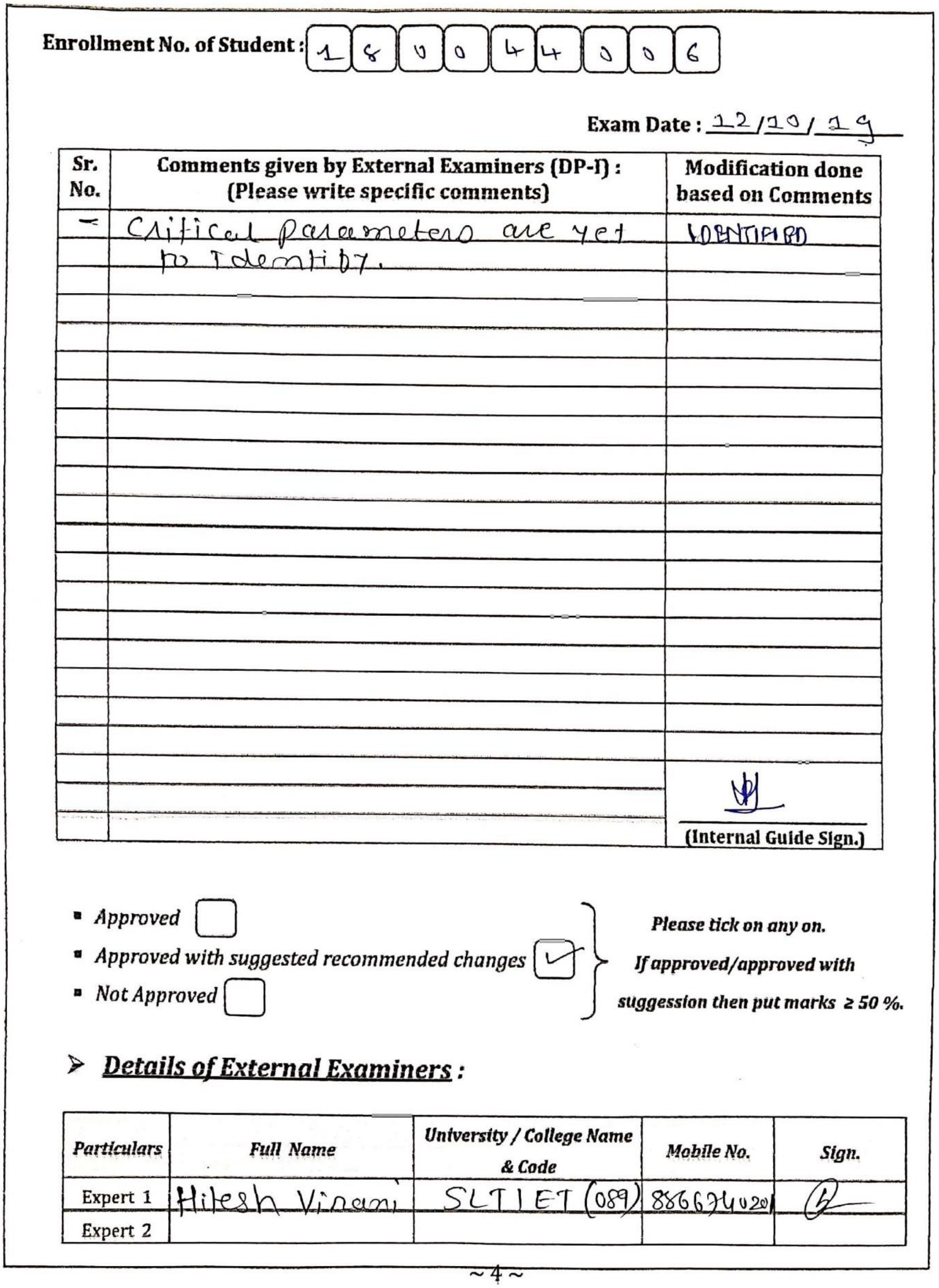
❖ **Comments of Dissertation Phase-1 (** 18MMEP)CC305 **(Semester 3)**

Exam Date : 12/10/ 19

Title : "Investigation on the effect of Alloying elements addition and Solidification time on modularity on 400/15 SGI casting"

1. Appropriateness of title with proposal. (Yes/ No) Yes
2. Whether the selected theme is appropriate according to the title ? (Yes / No) Yes
3. Justify rational of proposed research. (Yes/ No) Yes
4. Clarity of objectives. (Yes/ No) Yes

~ 3 ~



Enrollment No. of Student : 1 8 0 0 4 4 0 0 6

Exam Date : 12/10/19

Sr. No.	Comments given by External Examiners (DP-I) : (Please write specific comments)	Modification done based on Comments
–	Critical parameters are yet to Identify.	IDENTIFIED
		(Internal Guide Sign.)

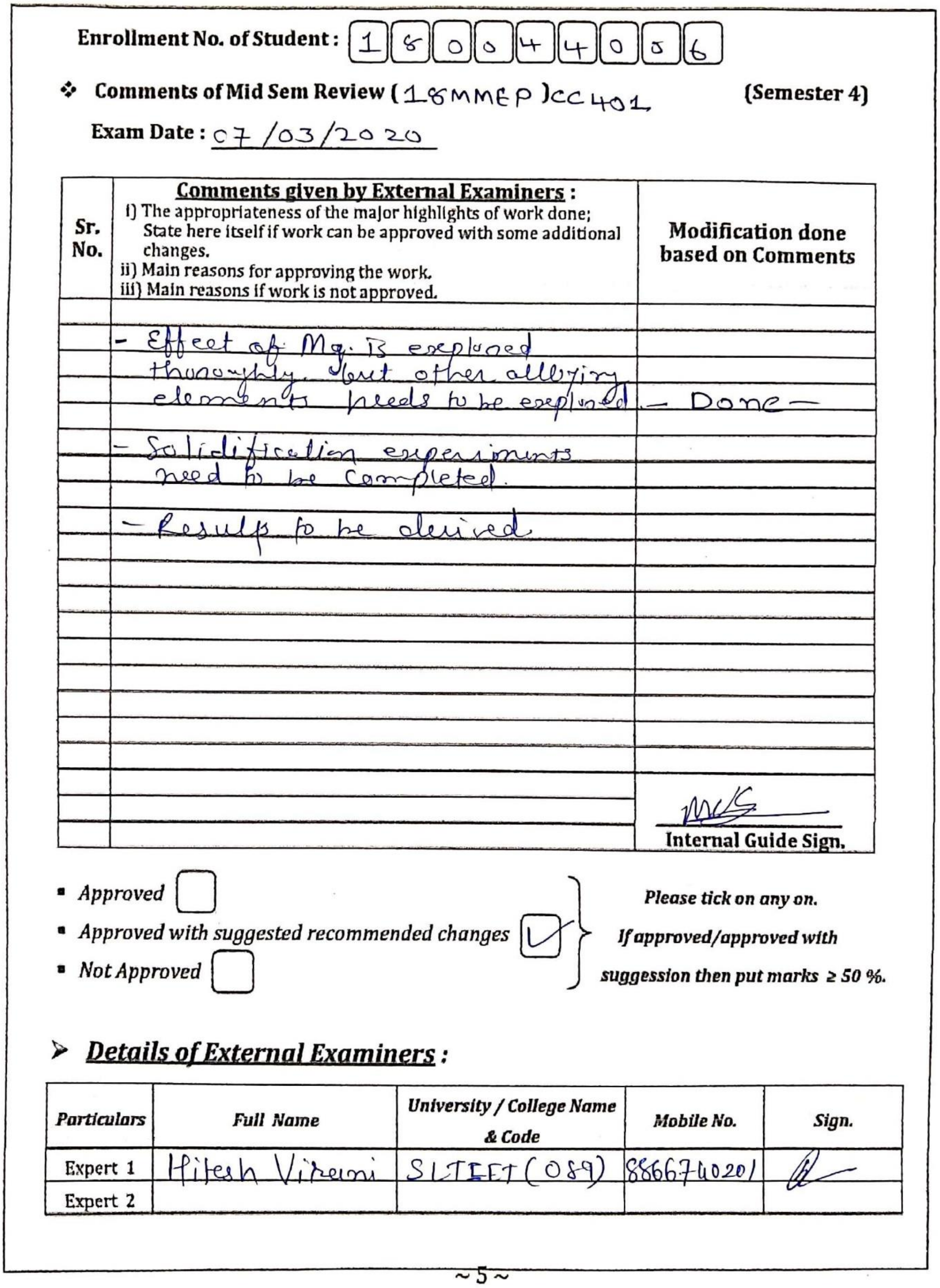
- *Approved* ☐
- *Approved with suggested recommended changes* ☑
- *Not Approved* ☐

Please tick on any on.
If approved/approved with suggession then put marks ≥ 50 %.

➢ *Details of External Examiners :*

Particulars	*Full Name*	*University / College Name & Code*	*Mobile No.*	*Sign.*
Expert 1	Hitesh Virani	SLTIET (089)	8866740201	
Expert 2				

~ 4 ~



Enrollment No. of Student : 1 8 0 0 4 4 0 5 6

❖ **Comments of Mid Sem Review (** 18MMEP **)** CC401 **(Semester 4)**

Exam Date : 07/03/2020

Sr. No.	**Comments given by External Examiners :** i) The appropriateness of the major highlights of work done; State here itself if work can be approved with some additional changes. ii) Main reasons for approving the work. iii) Main reasons if work is not approved.	**Modification done based on Comments**
	- Effect of Mg. is explored thoroughly. but other alloying elements needs to be explored	- Done -
	- Solidification experiments need to be completed.	
	- Results to be derived	
		Internal Guide Sign.

- *Approved* ☐
- *Approved with suggested recommended changes* ☑
- *Not Approved* ☐

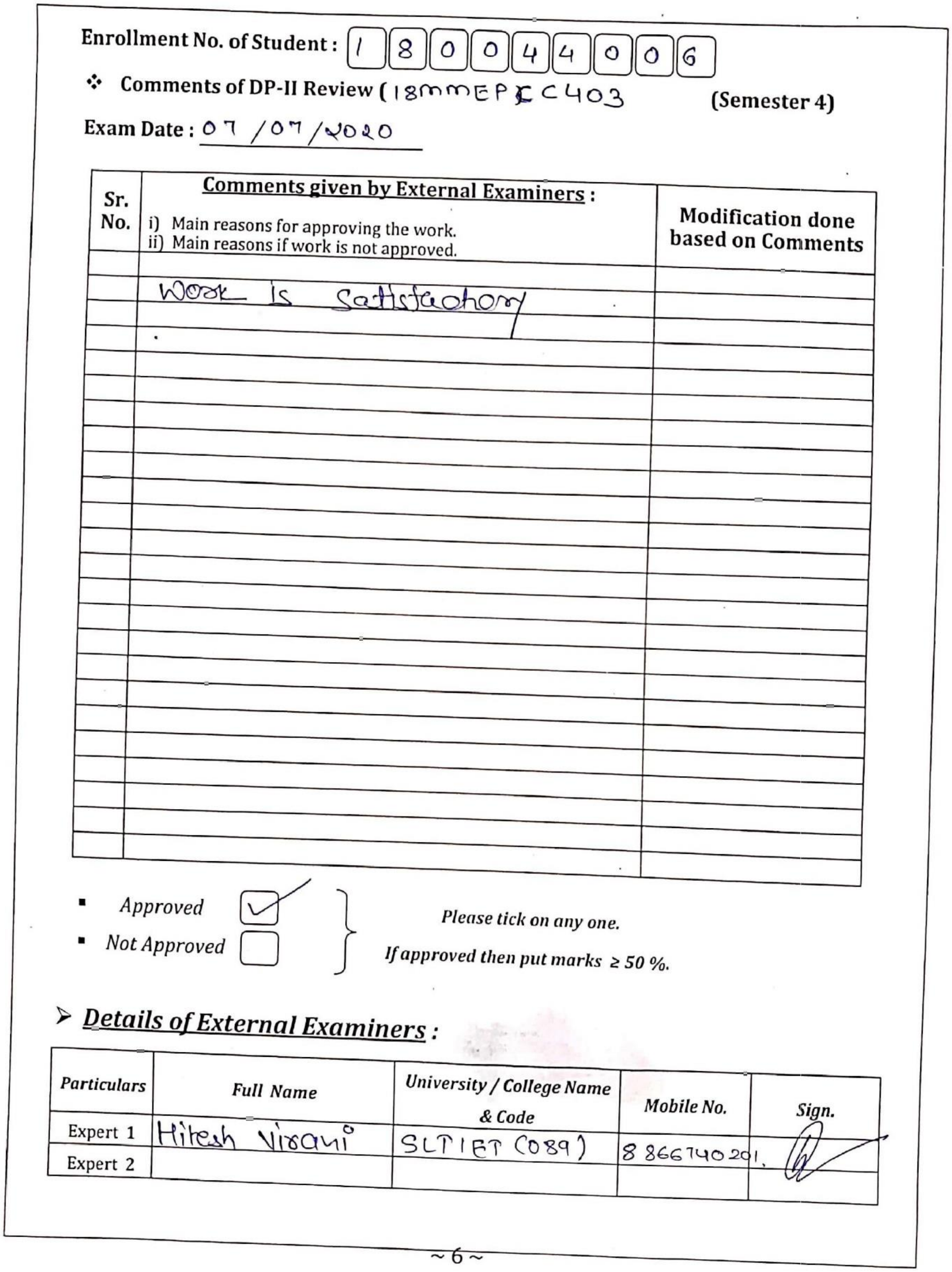
Please tick on any on.
If approved/approved with suggession then put marks ≥ 50 %.

➢ ***Details of External Examiners :***

Particulars	*Full Name*	*University / College Name & Code*	*Mobile No.*	*Sign.*
Expert 1	Hitesh Virani	SLTIET (089)	8866740201	
Expert 2				

~ 5 ~

Appendix A: Review Card



Enrollment No. of Student : 1 8 0 0 4 4 0 0 6

- **Comments of DP-II Review (** 18MMEPEC403 **(Semester 4)**

Exam Date : 07 /07/2020

Sr. No.	**Comments given by External Examiners :** i) Main reasons for approving the work. ii) Main reasons if work is not approved.	Modification done based on Comments
	Work is Satisfactory	

- *Approved* ☑
- *Not Approved* ☐

Please tick on any one.

If approved then put marks ≥ 50 %.

Details of External Examiners :

Particulars	*Full Name*	*University / College Name & Code*	*Mobile No.*	*Sign.*
Expert 1	Hitesh Virani	SLTIET (089)	8866740201.	
Expert 2				

~ 6 ~

Appendix B: Compliance Report

Comments given during Dissertation Phase-1 and Mid-Semester Review are given below with required actions taken for their fulfilment:

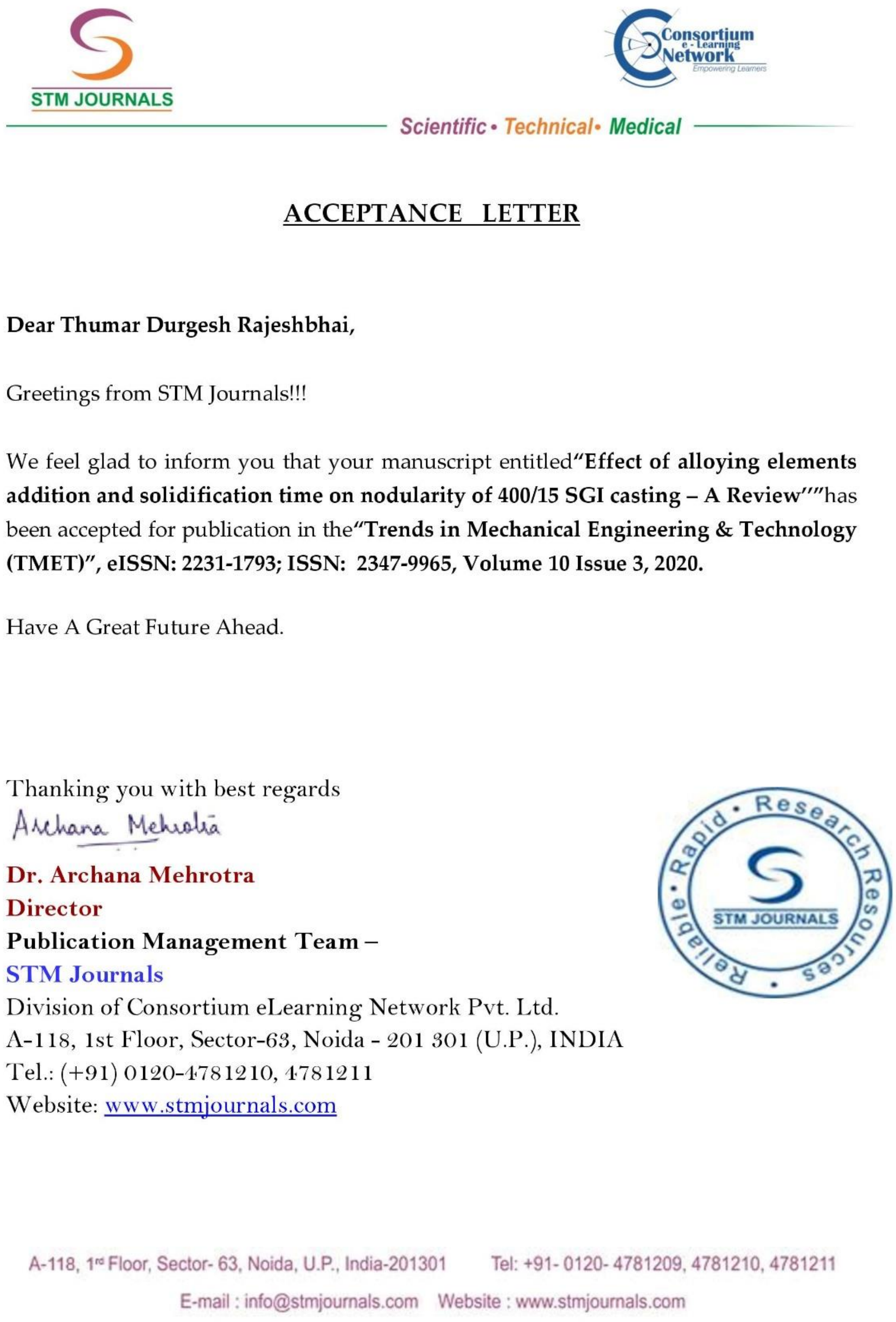
- **Comments for Dissertation Phase-1:**

Sr. No.	Comments Given	Actions
1	Critical parameters yet to identify	Important parameter identified

- **Comments for Mid-Semester Review:**

Sr. No.	Comments Given	Actions
1	Effect of Mg is explored thoroughly but other alloying elements needs to be explored	Sulfur , silicon, Pouring Temperature , And Pouring Time Also Affect Nodularity
2.	Solidification experiments needs to be completed	Completed
2	Results are to be derived	Done

Appendix C: Acceptance Letter



STM JOURNALS

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ACCEPTANCE LETTER

Dear Thumar Durgesh Rajeshbhai,

Greetings from STM Journals!!!

We feel glad to inform you that your manuscript entitled**"Effect of alloying elements addition and solidification time on nodularity of 400/15 SGI casting – A Review'"**has been accepted for publication in the**"Trends in Mechanical Engineering & Technology (TMET)", eISSN: 2231-1793; ISSN: 2347-9965, Volume 10 Issue 3, 2020.**

Have A Great Future Ahead.

Thanking you with best regards
Archana Mehrotra

Dr. Archana Mehrotra
Director
Publication Management Team –
STM Journals
Division of Consortium eLearning Network Pvt. Ltd.
A-118, 1st Floor, Sector-63, Noida - 201 301 (U.P.), INDIA
Tel.: (+91) 0120-4781210, 4781211
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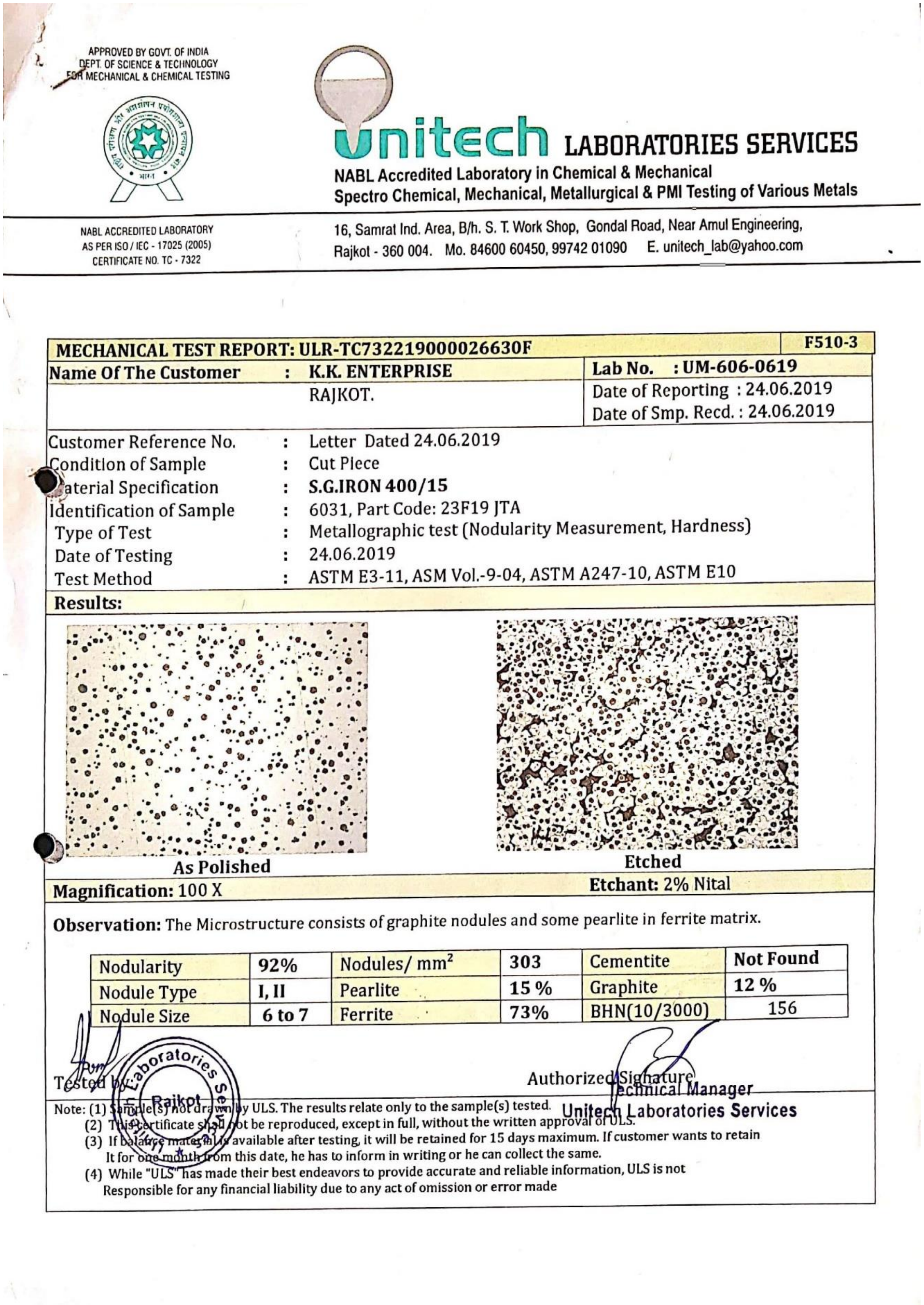
E-mail : info@stmjournals.com Website : www.stmjournals.com

Appendix D: Standard Result



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MECHANICAL TEST REPORT: ULR-TC732219000026630F **F510-3**

Name Of The Customer : **K.K. ENTERPRISE**
RAJKOT.

Lab No. : UM-606-0619
Date of Reporting : 24.06.2019
Date of Smp. Recd. : 24.06.2019

Customer Reference No. : Letter Dated 24.06.2019
Condition of Sample : Cut Piece
Material Specification : **S.G.IRON 400/15**
Identification of Sample : 6031, Part Code: 23F19 JTA
Type of Test : Metallographic test (Nodularity Measurement, Hardness)
Date of Testing : 24.06.2019
Test Method : ASTM E3-11, ASM Vol.-9-04, ASTM A247-10, ASTM E10

Results:

As Polished

Etched

Magnification: 100 X

Etchant: 2% Nital

Observation: The Microstructure consists of graphite nodules and some pearlite in ferrite matrix.

Nodularity	**92%**	Nodules/ mm^2	**303**	Cementite	**Not Found**
Nodule Type	**I, II**	Pearlite	**15 %**	Graphite	**12 %**
Nodule Size	**6 to 7**	Ferrite	**73%**	BHN(10/3000)	156

Tested by:

Laboratories Services Rajkot

Authorized Signature
Technical Manager
Unitech Laboratories Services

Note: (1) Sample(s) not drawn by ULS. The results relate only to the sample(s) tested.
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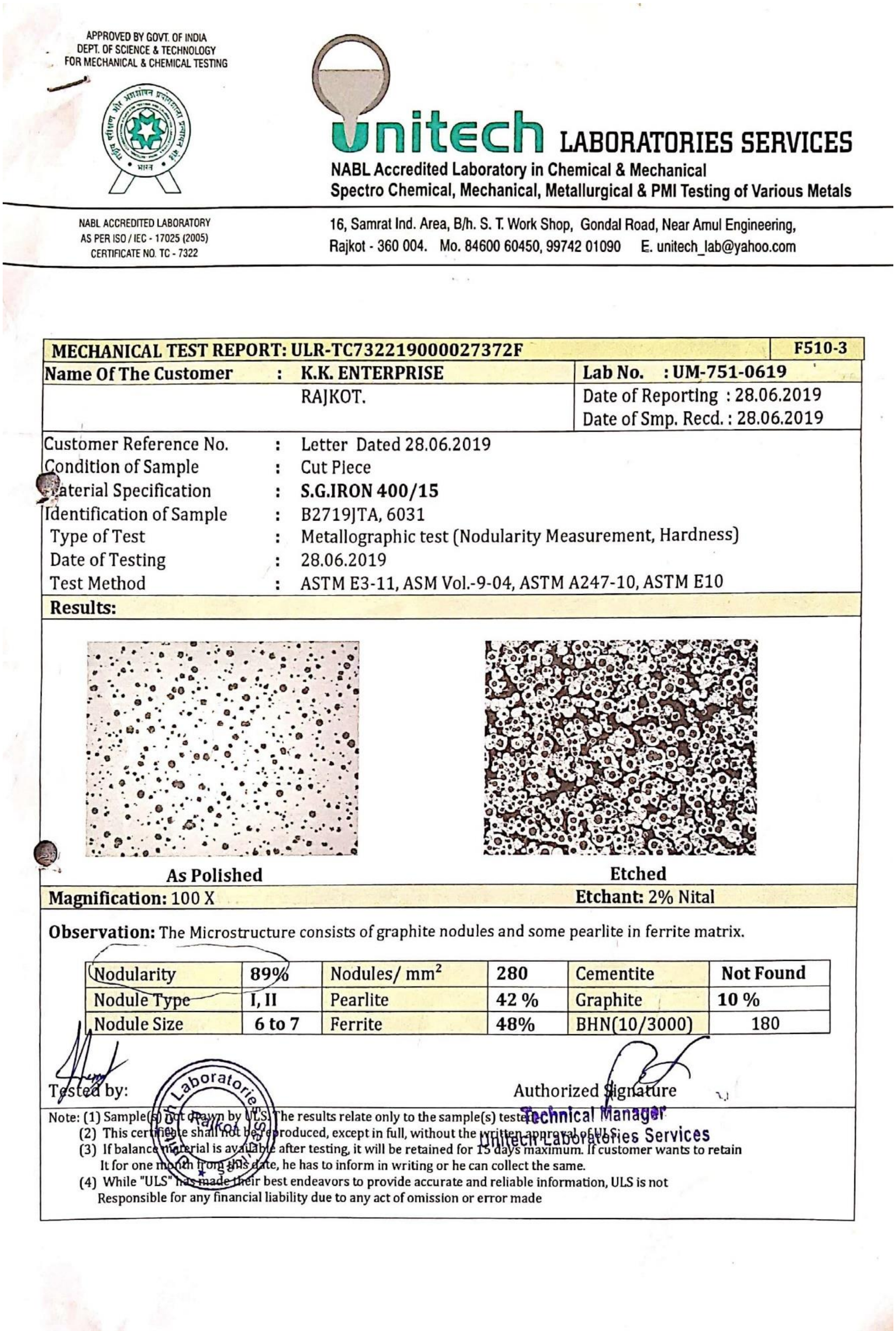
Appendix D: Standard Result



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MECHANICAL TEST REPORT: ULR-TC732219000027372F **F510-3**

Name Of The Customer : **K.K. ENTERPRISE**
RAJKOT.

Lab No. : **UM-751-0619**
Date of Reporting : 28.06.2019
Date of Smp. Recd. : 28.06.2019

Customer Reference No. : Letter Dated 28.06.2019
Condition of Sample : Cut Piece
Material Specification : **S.G.IRON 400/15**
Identification of Sample : B2719JTA, 6031
Type of Test : Metallographic test (Nodularity Measurement, Hardness)
Date of Testing : 28.06.2019
Test Method : ASTM E3-11, ASM Vol.-9-04, ASTM A247-10, ASTM E10

Results:

As Polished **Etched**

Magnification: 100 X **Etchant:** 2% Nital

Observation: The Microstructure consists of graphite nodules and some pearlite in ferrite matrix.

Nodularity	**89%**	Nodules/ mm^2	**280**	Cementite	**Not Found**
Nodule Type	**I, II**	Pearlite	**42 %**	Graphite	**10 %**
Nodule Size	**6 to 7**	Ferrite	**48%**	BHN(10/3000)	180

Tested by:

Authorized Signature
Technical Manager
Unitech Laboratories Services

Note: (1) Sample(s) not drawn by ULS. The results relate only to the sample(s) tested.
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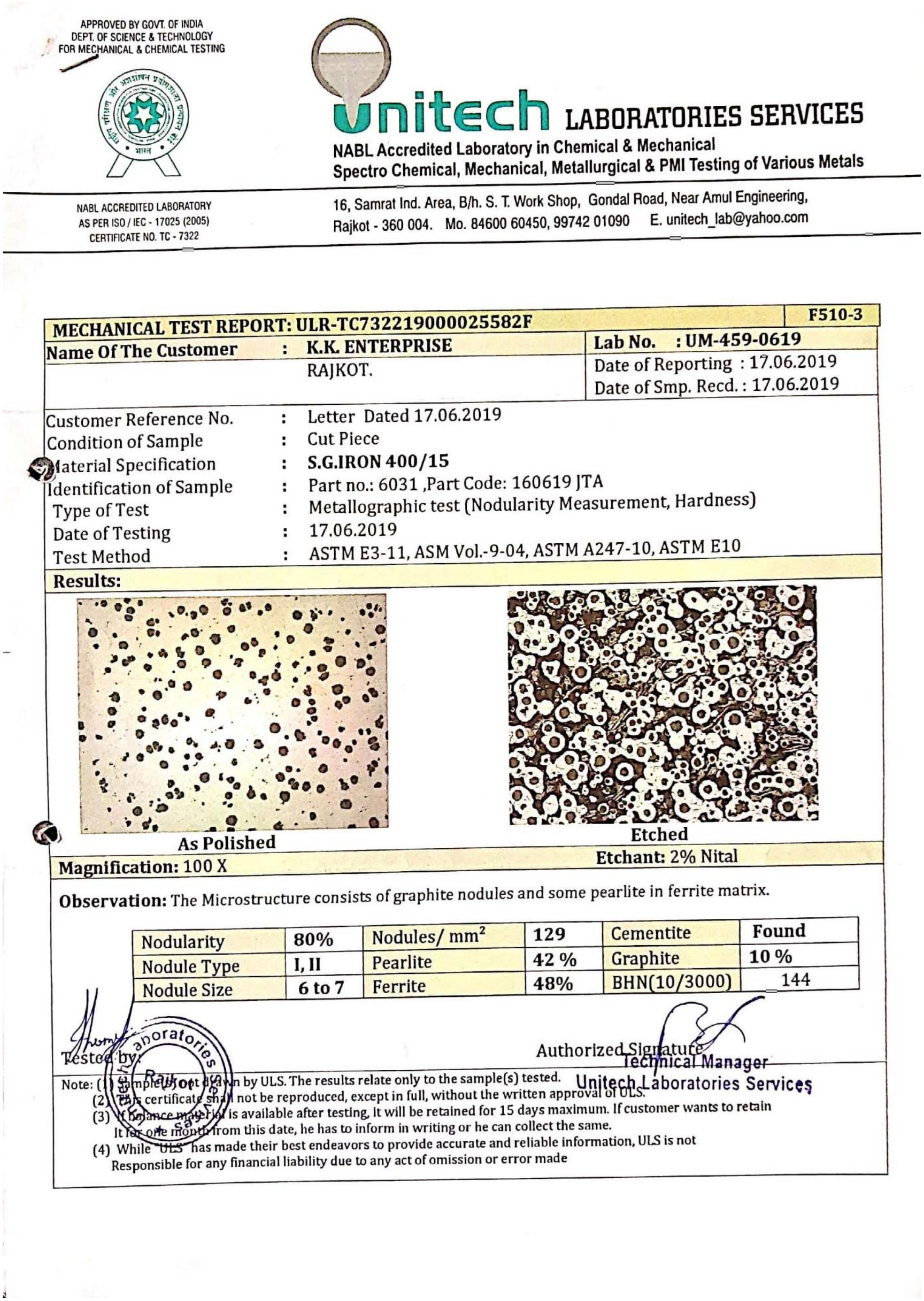
Appendix D: Standard Result



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MECHANICAL TEST REPORT: ULR-TC732219000025582F **F510-3**

Name Of The Customer : **K.K. ENTERPRISE**
RAJKOT.

Lab No. : **UM-459-0619**
Date of Reporting : 17.06.2019
Date of Smp. Recd. : 17.06.2019

Customer Reference No. : Letter Dated 17.06.2019
Condition of Sample : Cut Piece
Material Specification : **S.G.IRON 400/15**
Identification of Sample : Part no.: 6031 ,Part Code: 160619 JTA
Type of Test : Metallographic test (Nodularity Measurement, Hardness)
Date of Testing : 17.06.2019
Test Method : ASTM E3-11, ASM Vol.-9-04, ASTM A247-10, ASTM E10

Results:

As Polished **Etched**

Magnification: 100 X **Etchant:** 2% Nital

Observation: The Microstructure consists of graphite nodules and some pearlite in ferrite matrix.

Nodularity	**80%**	Nodules/ mm^2	**129**	Cementite	**Found**
Nodule Type	**I, II**	Pearlite	**42 %**	Graphite	**10 %**
Nodule Size	**6 to 7**	Ferrite	**48%**	BHN(10/3000)	144

Tested by: Authorized Signature
Technical Manager
Unitech Laboratories Services

Note: (1) Sample(s) not drawn by ULS. The results relate only to the sample(s) tested.
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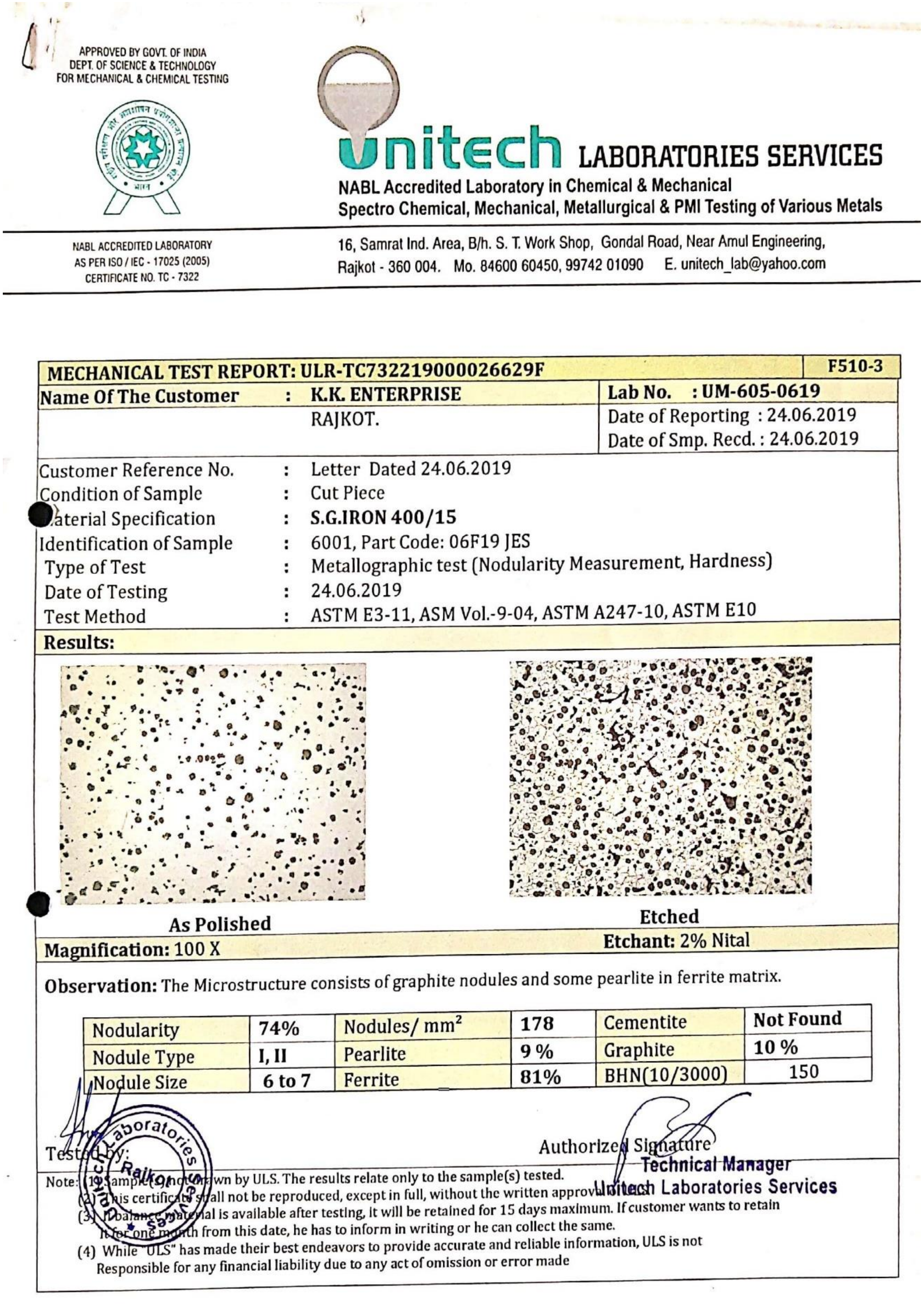
Appendix D: Standard Result



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MECHANICAL TEST REPORT: ULR-TC732219000026629F **F510-3**

Name Of The Customer : **K.K. ENTERPRISE**
RAJKOT.

Lab No. : **UM-605-0619**
Date of Reporting : 24.06.2019
Date of Smp. Recd. : 24.06.2019

Customer Reference No. : Letter Dated 24.06.2019
Condition of Sample : Cut Piece
Material Specification : **S.G.IRON 400/15**
Identification of Sample : 6001, Part Code: 06F19 JES
Type of Test : Metallographic test (Nodularity Measurement, Hardness)
Date of Testing : 24.06.2019
Test Method : ASTM E3-11, ASM Vol.-9-04, ASTM A247-10, ASTM E10

Results:

As Polished **Etched**

Magnification: 100 X **Etchant:** 2% Nital

Observation: The Microstructure consists of graphite nodules and some pearlite in ferrite matrix.

Nodularity	**74%**	Nodules/ mm^2	**178**	Cementite	**Not Found**
Nodule Type	**I, II**	Pearlite	**9 %**	Graphite	**10 %**
Nodule Size	**6 to 7**	Ferrite	**81%**	BHN(10/3000)	150

Tested by:

Authorized Signature
Technical Manager
Unitech Laboratories Services

Note: (1) Sample(s) not drawn by ULS. The results relate only to the sample(s) tested.
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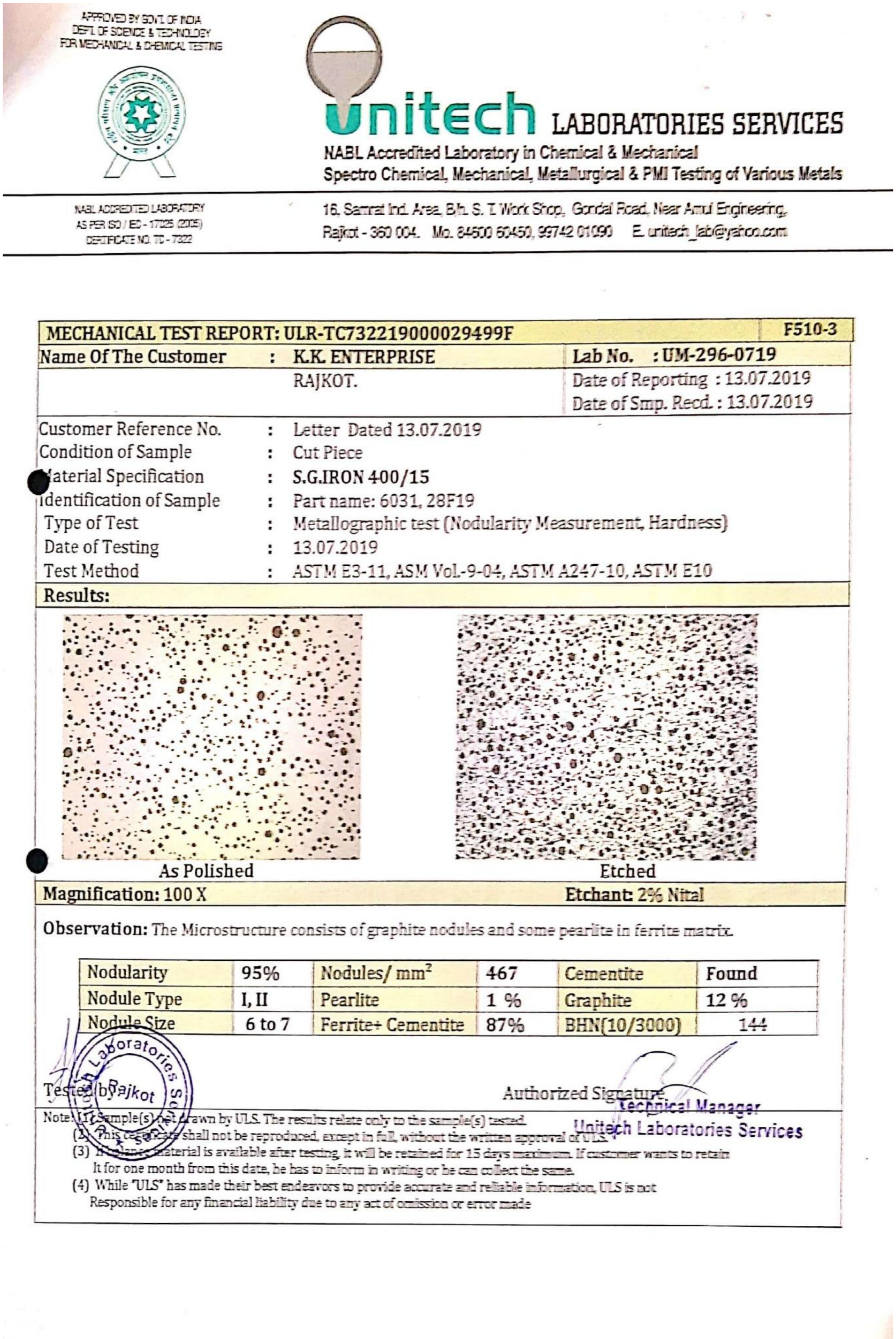
Appendix D: Standard Result



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MECHANICAL TEST REPORT: ULR-TC732219000029499F **F510-3**

Name Of The Customer	:	**K.K. ENTERPRISE** RAJKOT.	**Lab No. : UM-296-0719** Date of Reporting : 13.07.2019 Date of Smp. Recd. : 13.07.2019

Customer Reference No. : Letter Dated 13.07.2019
Condition of Sample : Cut Piece
Material Specification : **S.G.IRON 400/15**
Identification of Sample : Part name: 6031, 28F19
Type of Test : Metallographic test (Nodularity Measurement, Hardness)
Date of Testing : 13.07.2019
Test Method : ASTM E3-11, ASM Vol.-9-04, ASTM A247-10, ASTM E10

Results:

As Polished Etched

Magnification: 100 X **Etchant:** 2% Nital

Observation: The Microstructure consists of graphite nodules and some pearlite in ferrite matrix.

Nodularity	95%	Nodules/ mm^2	467	Cementite	Found
Nodule Type	I, II	Pearlite	1 %	Graphite	12 %
Nodule Size	6 to 7	Ferrite+ Cementite	87%	BHN(10/3000)	144

Tested by Rajkot

Authorized Signature
Technical Manager
Unitech Laboratories Services

Note: (1) Sample(s) not drawn by ULS. The results relate only to the sample(s) tested.
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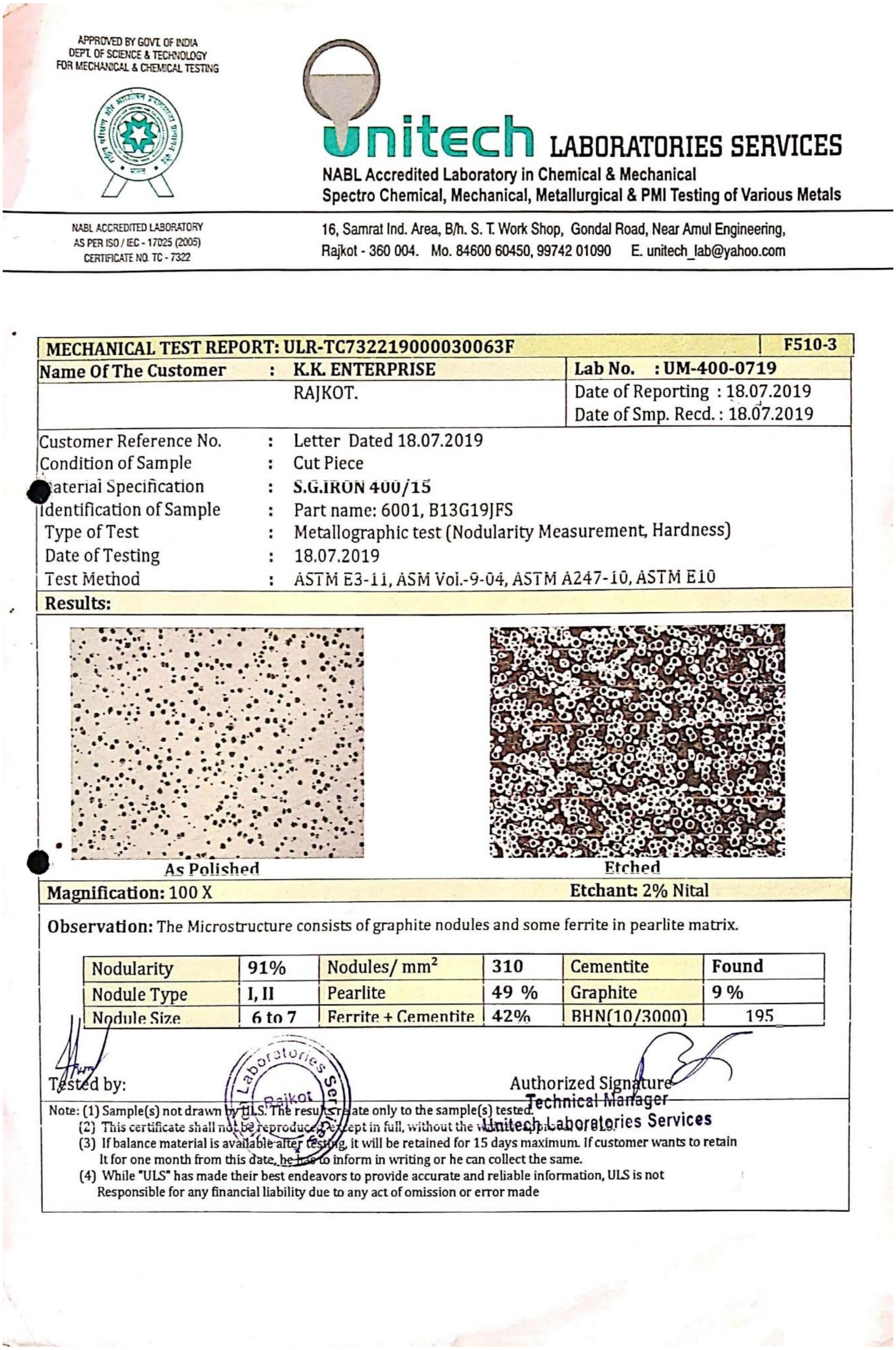
Appendix D: Standard Result



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MECHANICAL TEST REPORT: ULR-TC732219000030063F **F510-3**

Name Of The Customer : K.K. ENTERPRISE
RAJKOT.

Lab No. : UM-400-0719
Date of Reporting : 18.07.2019
Date of Smp. Recd. : 18.07.2019

Customer Reference No. : Letter Dated 18.07.2019
Condition of Sample : Cut Piece
Material Specification : **S.G.IRON 400/15**
Identification of Sample : Part name: 6001, B13G19JFS
Type of Test : Metallographic test (Nodularity Measurement, Hardness)
Date of Testing : 18.07.2019
Test Method : ASTM E3-11, ASM Vol.-9-04, ASTM A247-10, ASTM E10

Results:

As Polished

Etched

Magnification: 100 X

Etchant: 2% Nital

Observation: The Microstructure consists of graphite nodules and some ferrite in pearlite matrix.

Nodularity	**91%**	Nodules/ mm^2	**310**	Cementite	**Found**
Nodule Type	**I, II**	Pearlite	**49 %**	Graphite	**9 %**
Nodule Size	**6 to 7**	Ferrite + Cementite	**42%**	BHN(10/3000)	195

Tested by:

Authorized Signature
Technical Manager
Unitech Laboratories Services

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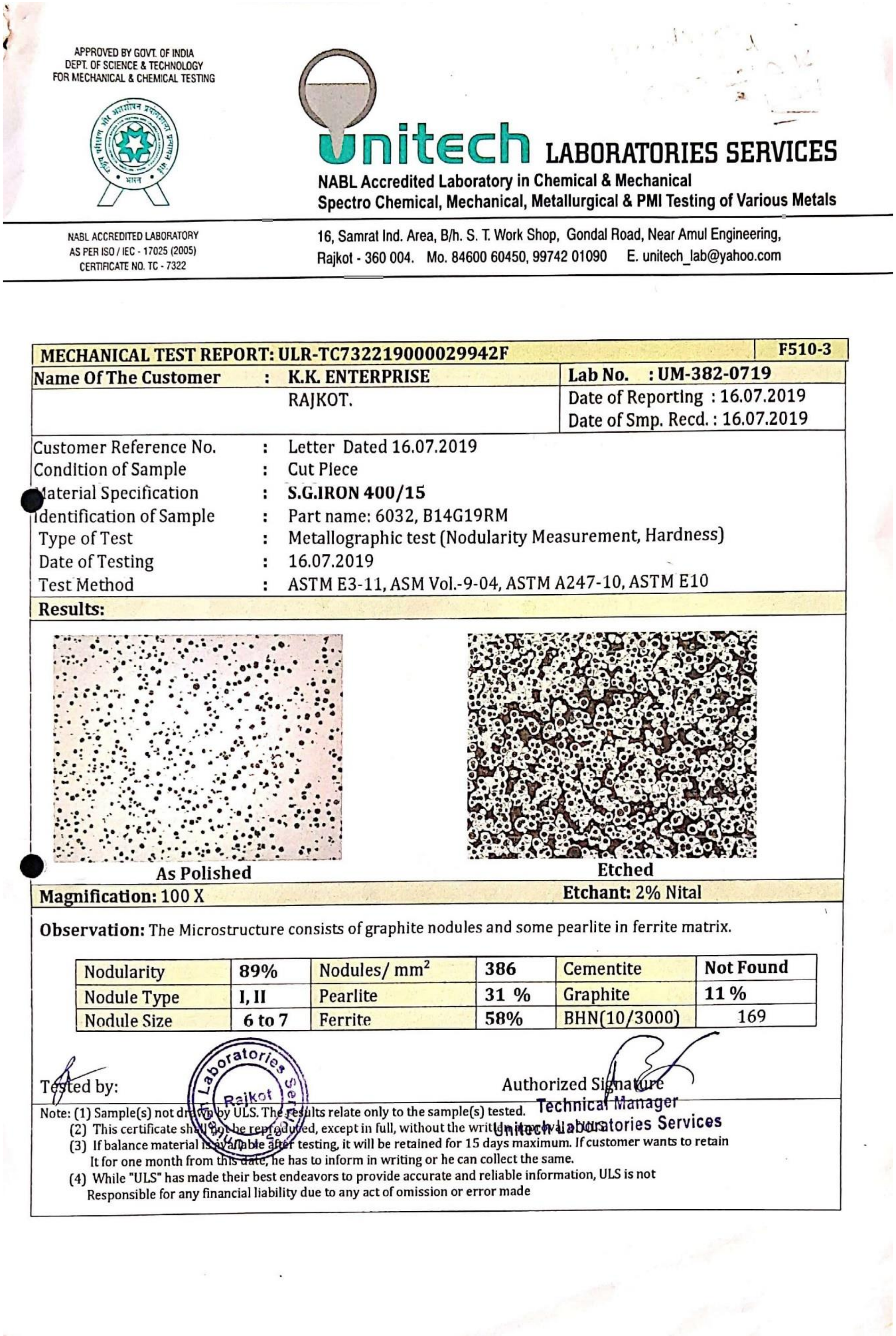
Appendix D: Standard Result



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MECHANICAL TEST REPORT: ULR-TC732219000029942F **F510-3**

Name Of The Customer	:	**K.K. ENTERPRISE** RAJKOT.	**Lab No. : UM-382-0719** Date of Reporting : 16.07.2019 Date of Smp. Recd. : 16.07.2019

Customer Reference No. : Letter Dated 16.07.2019
Condition of Sample : Cut Piece
Material Specification : **S.G.IRON 400/15**
Identification of Sample : Part name: 6032, B14G19RM
Type of Test : Metallographic test (Nodularity Measurement, Hardness)
Date of Testing : 16.07.2019
Test Method : ASTM E3-11, ASM Vol.-9-04, ASTM A247-10, ASTM E10

Results:

As Polished **Etched**

Magnification: 100 X **Etchant:** 2% Nital

Observation: The Microstructure consists of graphite nodules and some pearlite in ferrite matrix.

Nodularity	**89%**	Nodules/ mm^2	**386**	Cementite	**Not Found**
Nodule Type	**I, II**	Pearlite	**31 %**	Graphite	**11 %**
Nodule Size	**6 to 7**	Ferrite	**58%**	BHN(10/3000)	169

Tested by:

Authorized Signature
Technical Manager
Unitech Laboratories Services

Note: (1) Sample(s) not drawn by ULS. The results relate only to the sample(s) tested.
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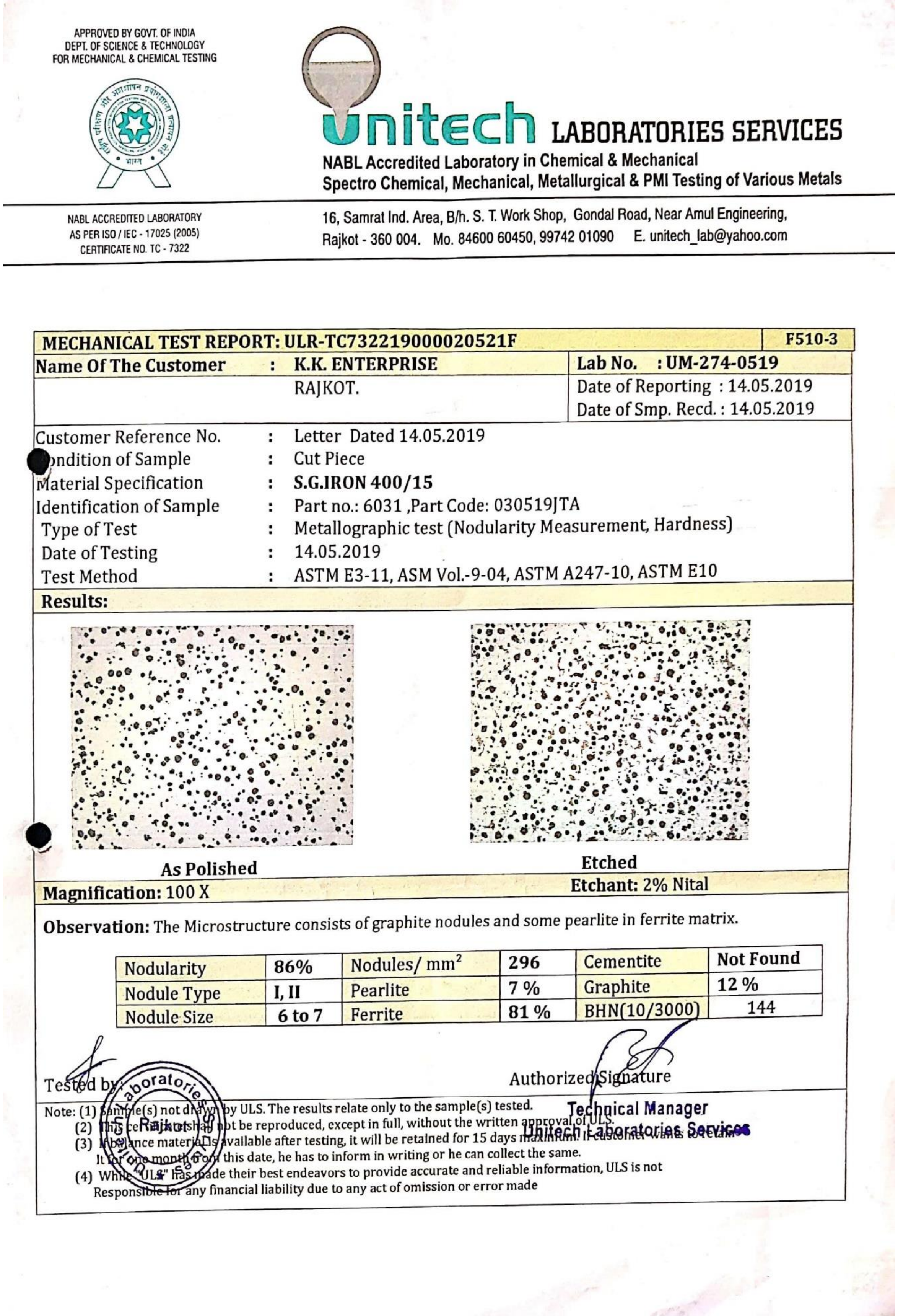

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MECHANICAL TEST REPORT: ULR-TC732219000020521F **F510-3**

Name Of The Customer	: **K.K. ENTERPRISE** RAJKOT.	**Lab No.**	**: UM-274-0519**
		Date of Reporting	: 14.05.2019
		Date of Smp. Recd.	: 14.05.2019

Customer Reference No. : Letter Dated 14.05.2019
Condition of Sample : Cut Piece
Material Specification : **S.G.IRON 400/15**
Identification of Sample : Part no.: 6031 ,Part Code: 030519JTA
Type of Test : Metallographic test (Nodularity Measurement, Hardness)
Date of Testing : 14.05.2019
Test Method : ASTM E3-11, ASM Vol.-9-04, ASTM A247-10, ASTM E10

Results:

As Polished **Etched**

Magnification: 100 X **Etchant:** 2% Nital

Observation: The Microstructure consists of graphite nodules and some pearlite in ferrite matrix.

Nodularity	**86%**	Nodules/ mm^2	**296**	Cementite	**Not Found**
Nodule Type	**I, II**	Pearlite	**7 %**	Graphite	**12 %**
Nodule Size	**6 to 7**	Ferrite	**81 %**	BHN(10/3000)	144

Tested by: Authorized Signature

Technical Manager
Unitech Laboratories Services

Unitech Laboratories Services Rajkot

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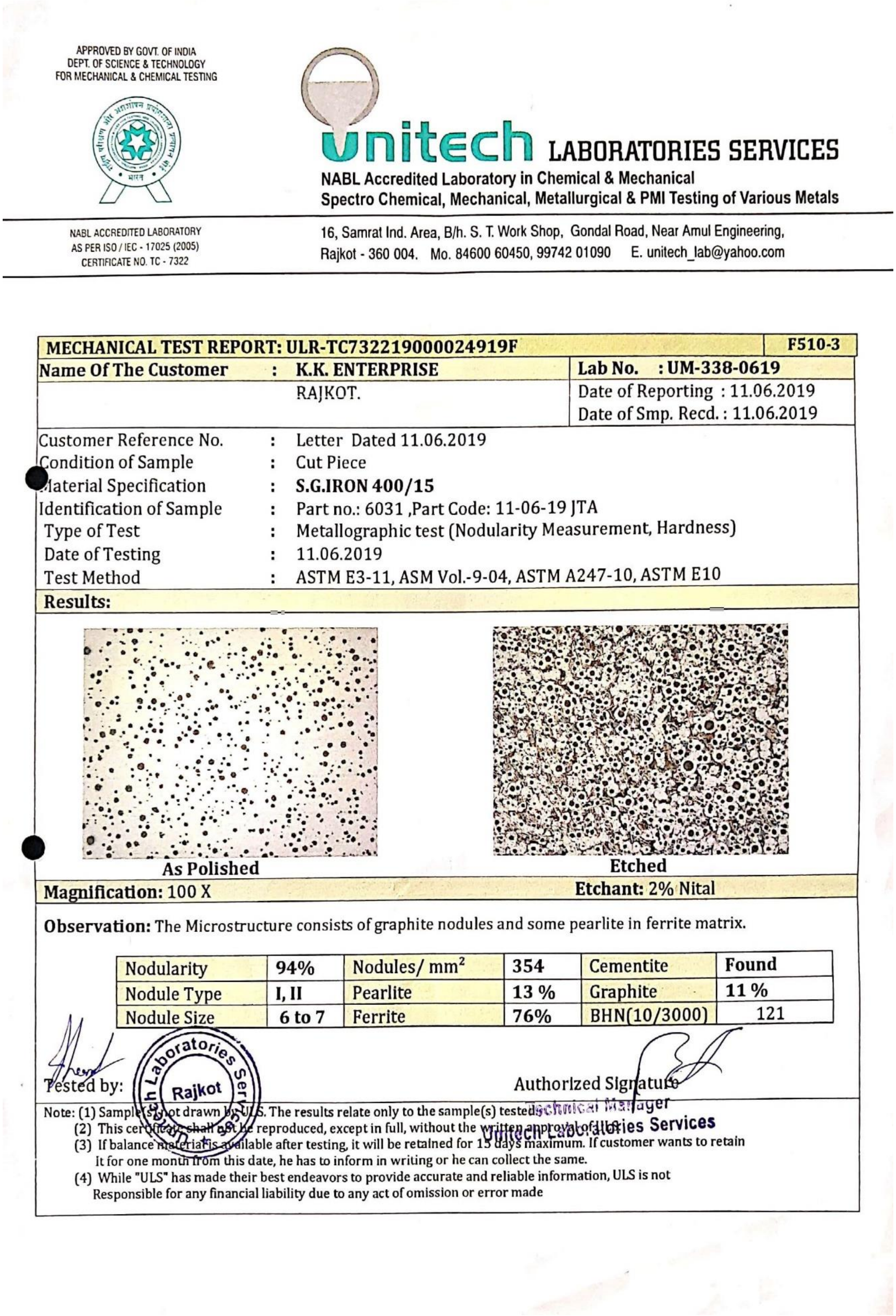
Appendix D: Standard Result



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MECHANICAL TEST REPORT: ULR-TC732219000024919F **F510-3**

Name Of The Customer : **K.K. ENTERPRISE**
RAJKOT.

Lab No. : **UM-338-0619**
Date of Reporting : 11.06.2019
Date of Smp. Recd. : 11.06.2019

Customer Reference No. : Letter Dated 11.06.2019
Condition of Sample : Cut Piece
Material Specification : **S.G.IRON 400/15**
Identification of Sample : Part no.: 6031 ,Part Code: 11-06-19 JTA
Type of Test : Metallographic test (Nodularity Measurement, Hardness)
Date of Testing : 11.06.2019
Test Method : ASTM E3-11, ASM Vol.-9-04, ASTM A247-10, ASTM E10

Results:

As Polished **Etched**

Magnification: 100 X **Etchant:** 2% Nital

Observation: The Microstructure consists of graphite nodules and some pearlite in ferrite matrix.

Nodularity	**94%**	Nodules/ mm^2	**354**	Cementite	**Found**
Nodule Type	**I, II**	Pearlite	**13 %**	Graphite	**11 %**
Nodule Size	**6 to 7**	Ferrite	**76%**	BHN(10/3000)	121

Tested by:

Authorized Signature
Technical Manager
Unitech Laboratories Services

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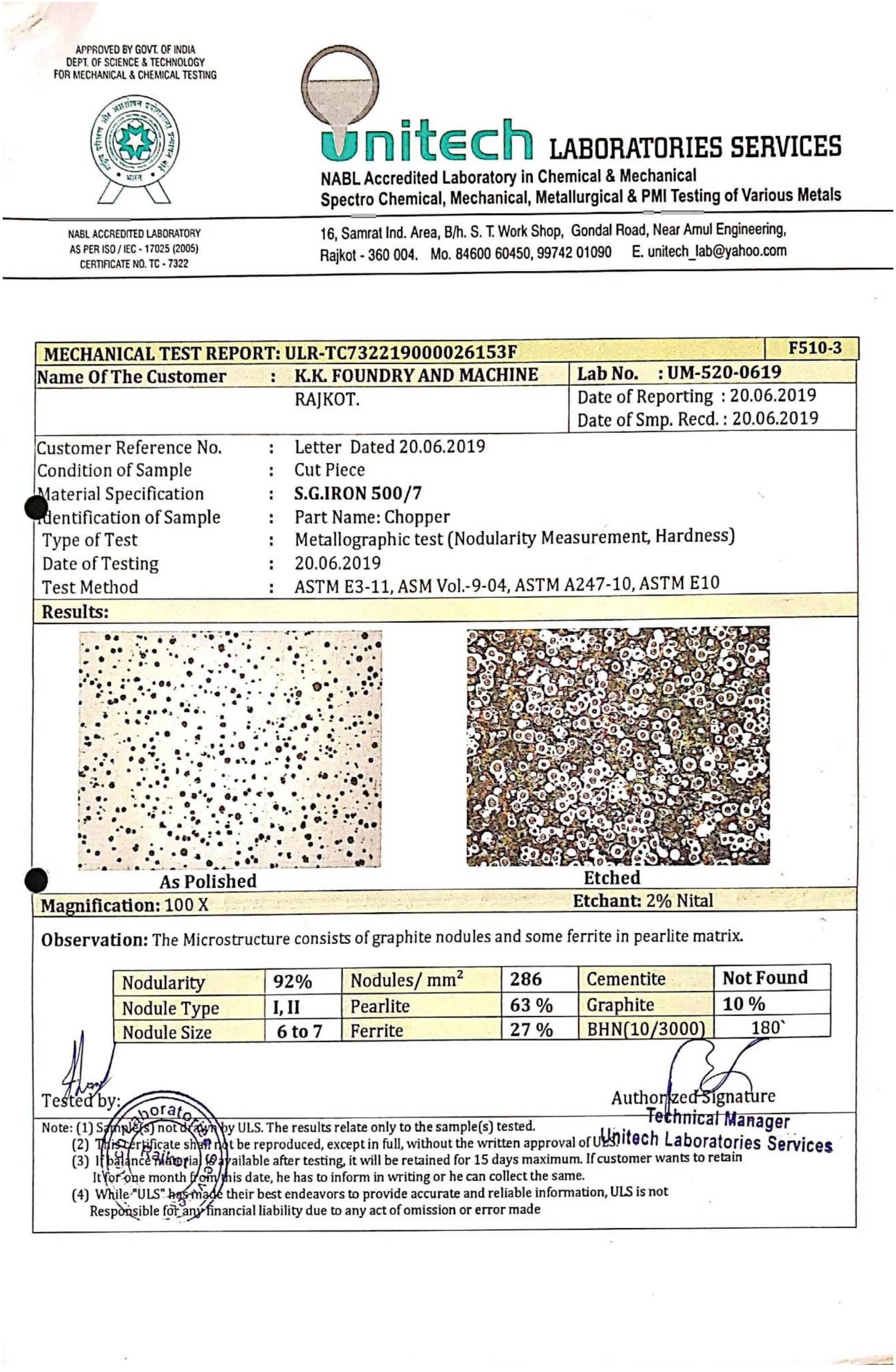
(4) While "ULS" has made their best endeavors to provide accurate and reliable information, ULS is not Responsible for any financial liability due to any act of omission or error made

Appendix D: Standard Result



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Rajkot - 360 004. Mo. 84600 60450, 99742 01090 E. unitech_lab@yahoo.com

MECHANICAL TEST REPORT: ULR-TC732219000026153F **F510-3**

Name Of The Customer	:	**K.K. FOUNDRY AND MACHINE** RAJKOT.	**Lab No. : UM-520-0619** Date of Reporting : 20.06.2019 Date of Smp. Recd. : 20.06.2019

Customer Reference No.	:	Letter Dated 20.06.2019
Condition of Sample	:	Cut Piece
Material Specification	:	**S.G.IRON 500/7**
Identification of Sample	:	Part Name: Chopper
Type of Test	:	Metallographic test (Nodularity Measurement, Hardness)
Date of Testing	:	20.06.2019
Test Method	:	ASTM E3-11, ASM Vol.-9-04, ASTM A247-10, ASTM E10

Results:

As Polished

Etched

Magnification: 100 X

Etchant: 2% Nital

Observation: The Microstructure consists of graphite nodules and some ferrite in pearlite matrix.

Nodularity	92%	Nodules/ mm²	286	Cementite	Not Found
Nodule Type	I, II	Pearlite	63 %	Graphite	10 %
Nodule Size	6 to 7	Ferrite	27 %	BHN(10/3000)	180`

Tested by:

Authorized Signature
Technical Manager
Unitech Laboratories Services

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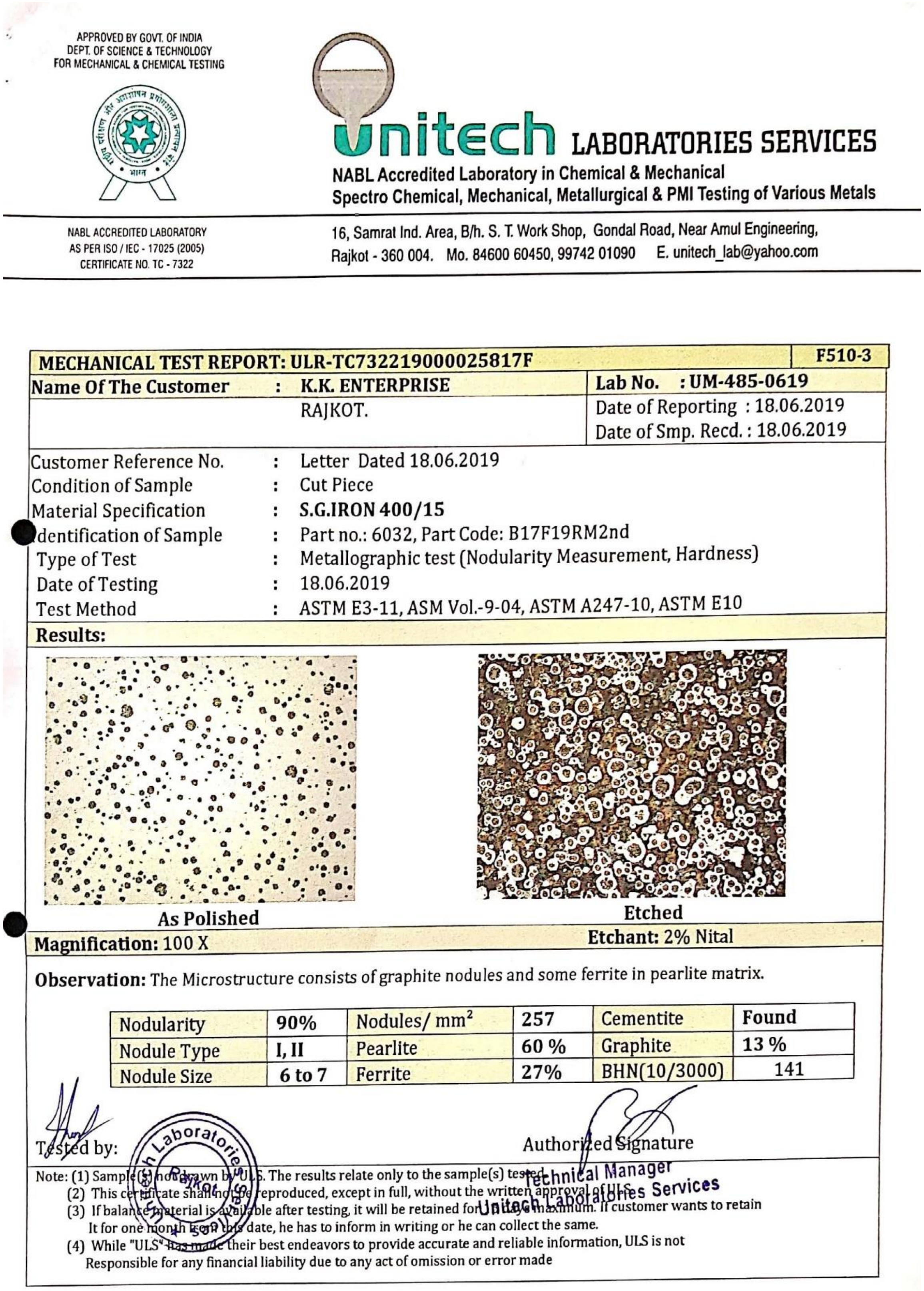

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MECHANICAL TEST REPORT: ULR-TC732219000025817F **F510-3**

Name Of The Customer : **K.K. ENTERPRISE**
RAJKOT.

Lab No. : UM-485-0619
Date of Reporting : 18.06.2019
Date of Smp. Recd. : 18.06.2019

Customer Reference No. : Letter Dated 18.06.2019
Condition of Sample : Cut Piece
Material Specification : **S.G.IRON 400/15**
Identification of Sample : Part no.: 6032, Part Code: B17F19RM2nd
Type of Test : Metallographic test (Nodularity Measurement, Hardness)
Date of Testing : 18.06.2019
Test Method : ASTM E3-11, ASM Vol.-9-04, ASTM A247-10, ASTM E10

Results:

As Polished

Etched

Magnification: 100 X

Etchant: 2% Nital

Observation: The Microstructure consists of graphite nodules and some ferrite in pearlite matrix.

Nodularity	**90%**	Nodules/ mm^2	**257**	Cementite	**Found**
Nodule Type	**I, II**	Pearlite	**60 %**	Graphite	**13 %**
Nodule Size	**6 to 7**	Ferrite	**27%**	BHN(10/3000)	141

Tested by:

Authorized Signature

Technical Manager
Unitech Laboratories Services

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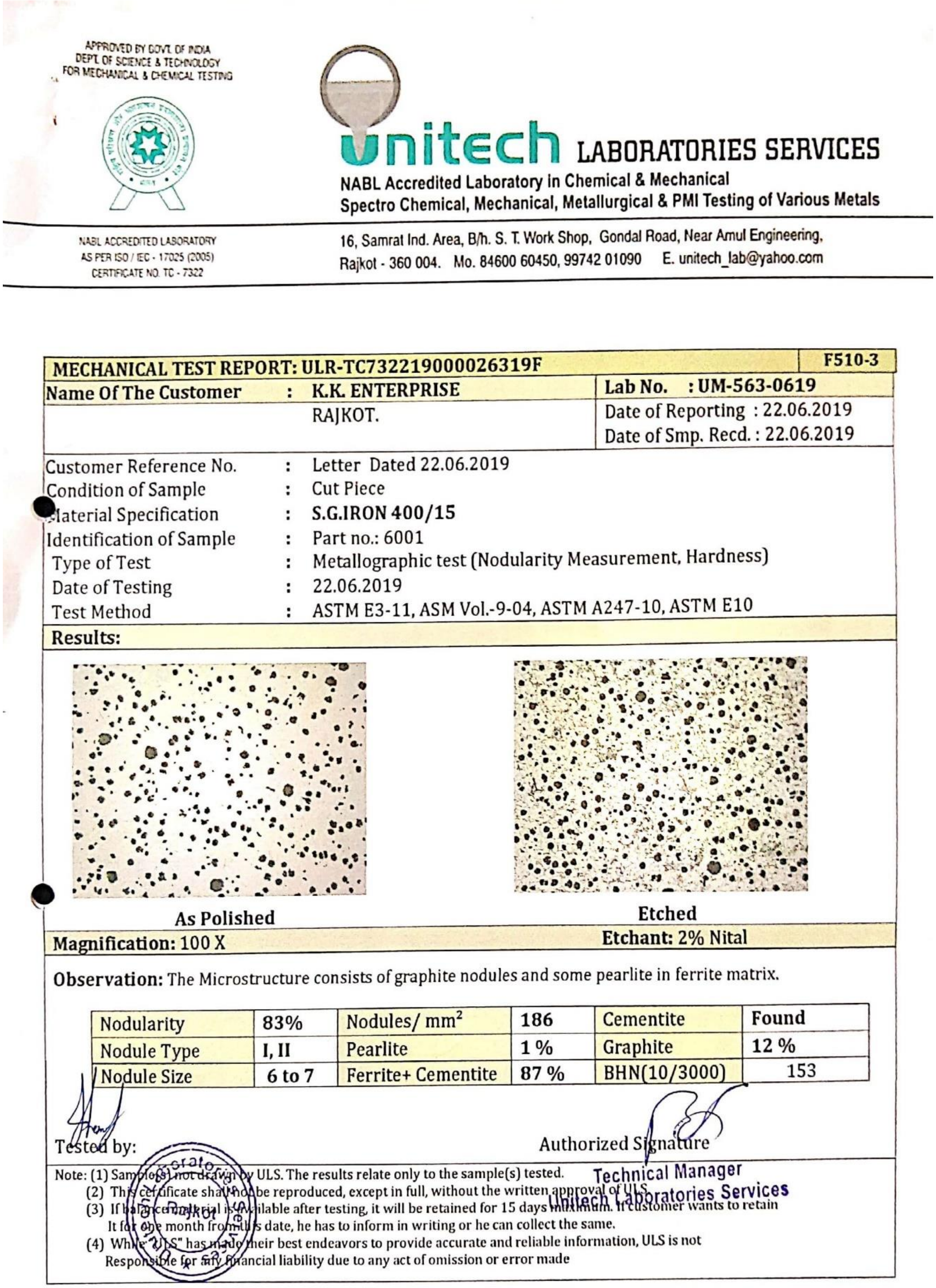
Appendix D: Standard Result



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MECHANICAL TEST REPORT: ULR-TC7322190000026319F **F510-3**

Name Of The Customer : K.K. ENTERPRISE
RAJKOT.

Lab No. : UM-563-0619
Date of Reporting : 22.06.2019
Date of Smp. Recd. : 22.06.2019

Customer Reference No. : Letter Dated 22.06.2019
Condition of Sample : Cut Piece
Material Specification : **S.G.IRON 400/15**
Identification of Sample : Part no.: 6001
Type of Test : Metallographic test (Nodularity Measurement, Hardness)
Date of Testing : 22.06.2019
Test Method : ASTM E3-11, ASM Vol.-9-04, ASTM A247-10, ASTM E10

Results:

As Polished **Etched**

Magnification: 100 X **Etchant:** 2% Nital

Observation: The Microstructure consists of graphite nodules and some pearlite in ferrite matrix.

Nodularity	**83%**	Nodules/ mm^2	**186**	Cementite	**Found**
Nodule Type	**I, II**	Pearlite	**1 %**	Graphite	**12 %**
Nodule Size	**6 to 7**	Ferrite+ Cementite	**87 %**	BHN(10/3000)	153

Tested by:

Authorized Signature

Technical Manager
Unitech Laboratories Services

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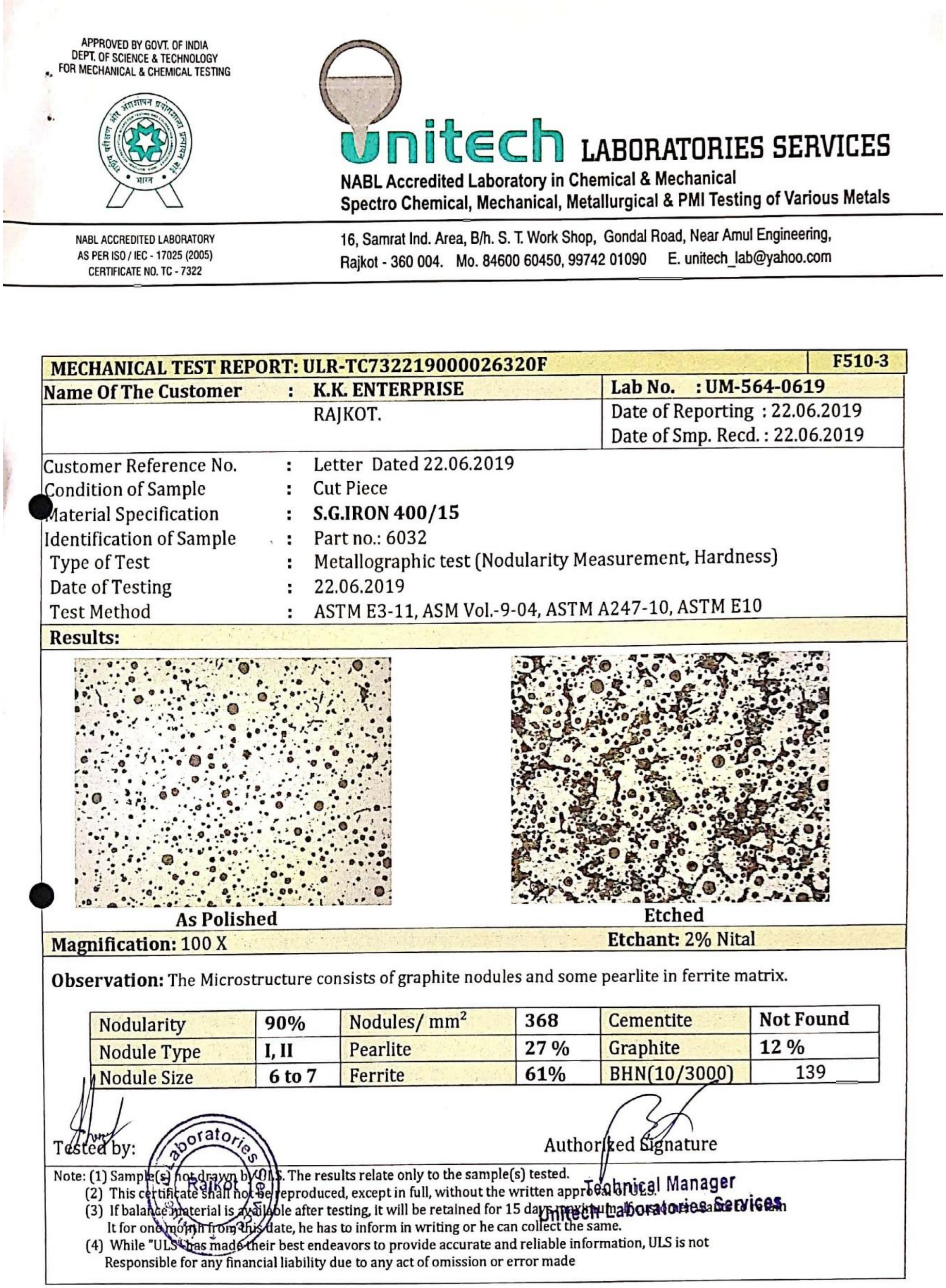
Appendix D: Standard Result



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MECHANICAL TEST REPORT: ULR-TC732219000026320F **F510-3**

Name Of The Customer : **K.K. ENTERPRISE**
RAJKOT.

Lab No. : **UM-564-0619**
Date of Reporting : 22.06.2019
Date of Smp. Recd. : 22.06.2019

Customer Reference No. : Letter Dated 22.06.2019
Condition of Sample : Cut Piece
Material Specification : **S.G.IRON 400/15**
Identification of Sample : Part no.: 6032
Type of Test : Metallographic test (Nodularity Measurement, Hardness)
Date of Testing : 22.06.2019
Test Method : ASTM E3-11, ASM Vol.-9-04, ASTM A247-10, ASTM E10

Results:

As Polished **Etched**

Magnification: 100 X **Etchant:** 2% Nital

Observation: The Microstructure consists of graphite nodules and some pearlite in ferrite matrix.

Nodularity	**90%**	Nodules/ mm^2	**368**	Cementite	**Not Found**
Nodule Type	**I, II**	Pearlite	**27 %**	Graphite	**12 %**
Nodule Size	**6 to 7**	Ferrite	**61%**	BHN(10/3000)	139

Tested by:

Laboratories Rajkot

Authorized Signature

Technical Manager
Unitech Laboratories Services

Note: (1) Sample(s) not drawn by ULS. The results relate only to the sample(s) tested.
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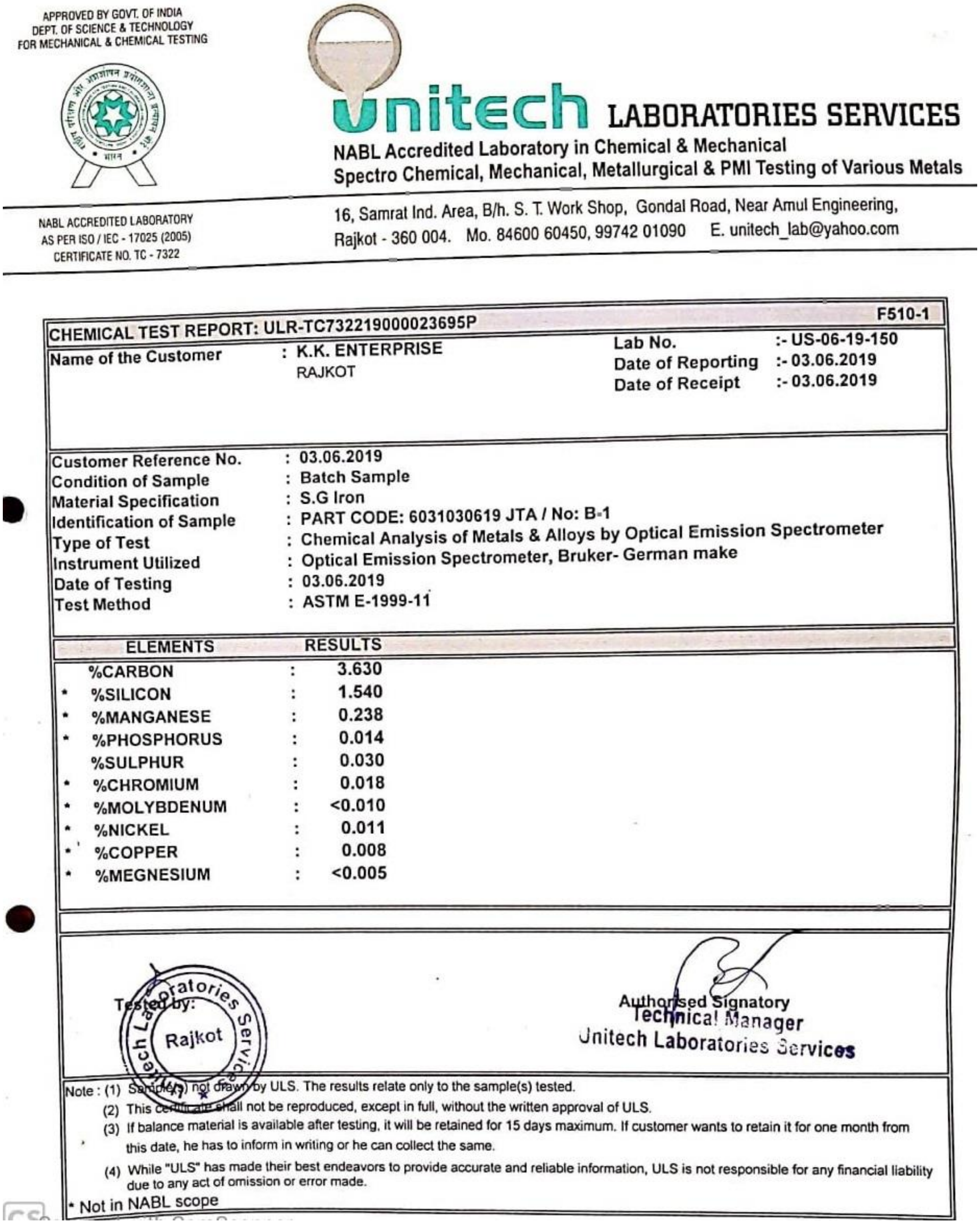
Appendix D: Standard Result



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CHEMICAL TEST REPORT: ULR-TC732219000023695P F510-1

Name of the Customer : K.K. ENTERPRISE
RAJKOT

Lab No. :- US-06-19-150
Date of Reporting :- 03.06.2019
Date of Receipt :- 03.06.2019

Customer Reference No. : 03.06.2019
Condition of Sample : Batch Sample
Material Specification : S.G Iron
Identification of Sample : PART CODE: 6031030619 JTA / No: B-1
Type of Test : Chemical Analysis of Metals & Alloys by Optical Emission Spectrometer
Instrument Utilized : Optical Emission Spectrometer, Bruker- German make
Date of Testing : 03.06.2019
Test Method : ASTM E-1999-11

ELEMENTS		RESULTS
%CARBON	:	3.630
* %SILICON	:	1.540
* %MANGANESE	:	0.238
* %PHOSPHORUS	:	0.014
%SULPHUR	:	0.030
* %CHROMIUM	:	0.018
* %MOLYBDENUM	:	<0.010
* %NICKEL	:	0.011
* %COPPER	:	0.008
* %MEGNESIUM	:	<0.005

Tested by:

Unitech Laboratories Services Rajkot

Authorised Signatory
Technical Manager
Unitech Laboratories Services

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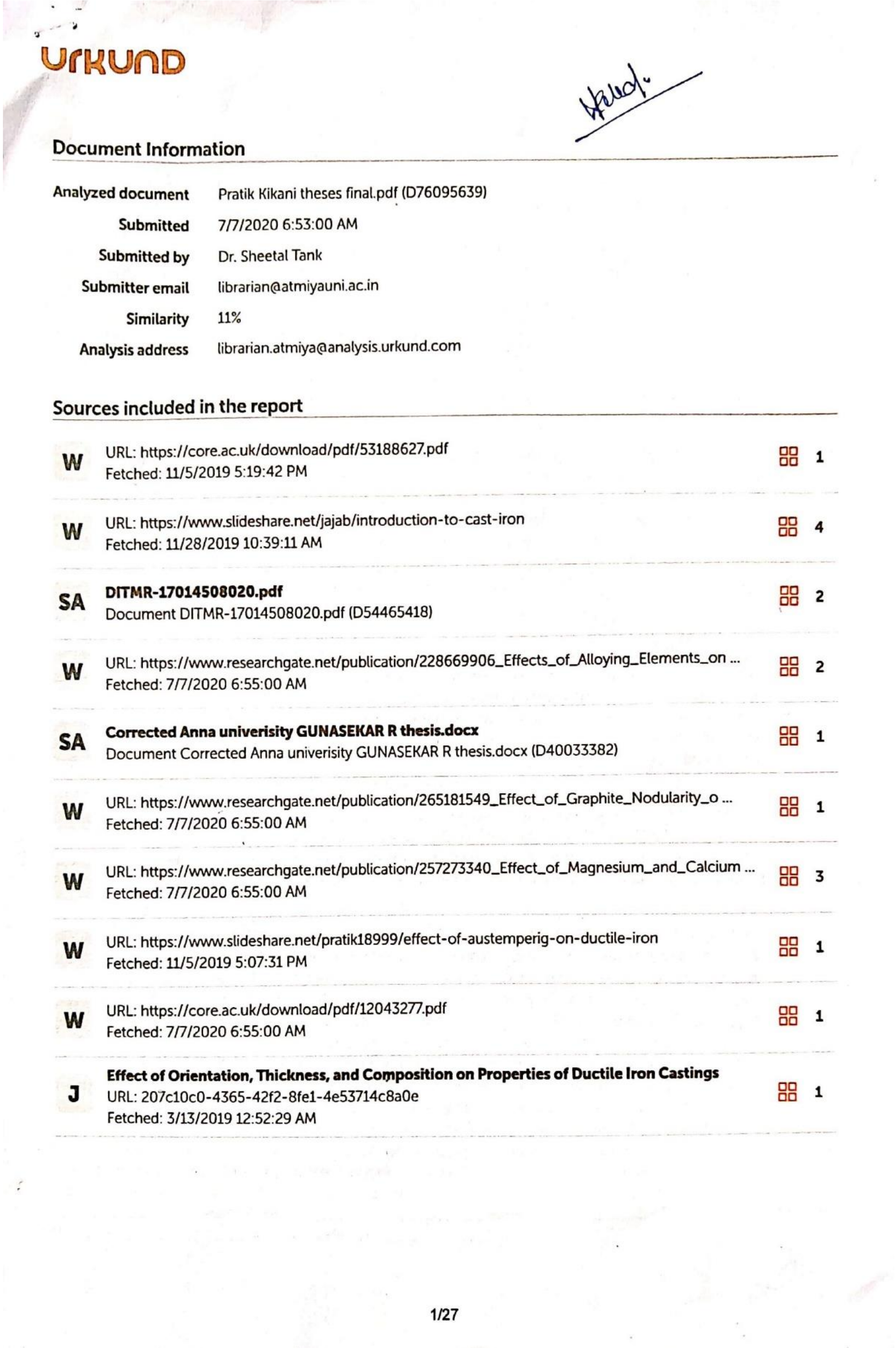
* Not in NABL scope

Appendix E: Plagiarism



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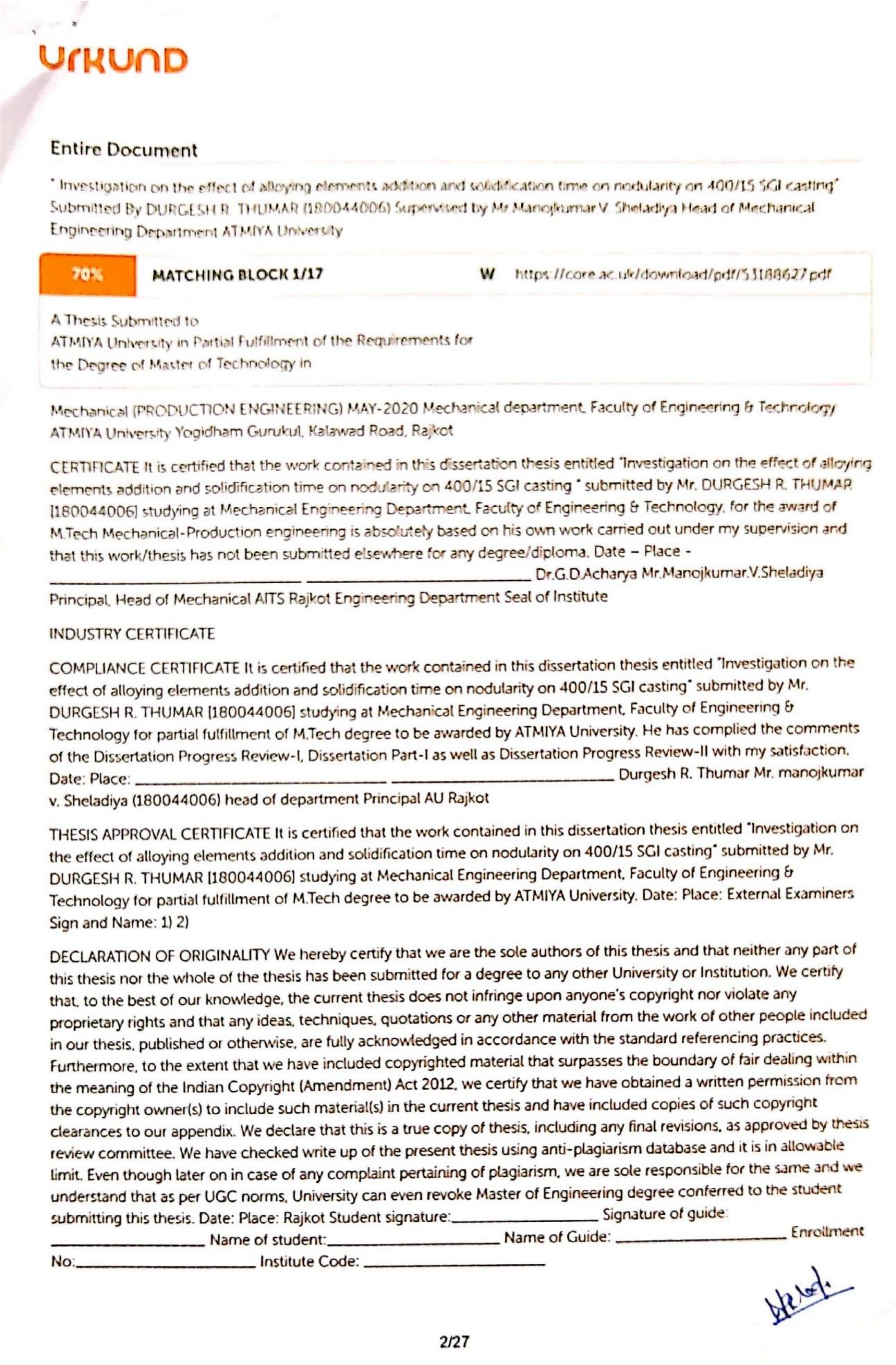
Appendix E: Plagiarism



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Entire Document

" Investigation on the effect of alloying elements addition and solidification time on nodularity on 400/15 SGI casting" Submitted By DURGESH R. THUMAR (180044006) Supervised by Mr Manojkumar V. Sheladiya Head of Mechanical Engineering Department ATMIYA University

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A Thesis Submitted to
ATMIYA University in Partial Fulfillment of the Requirements for
the Degree of Master of Technology in

Mechanical (PRODUCTION ENGINEERING) MAY-2020 Mechanical department. Faculty of Engineering & Technology ATMIYA University Yogidham Gurukul, Kalawad Road, Rajkot

CERTIFICATE It is certified that the work contained in this dissertation thesis entitled "Investigation on the effect of alloying elements addition and solidification time on nodularity on 400/15 SGI casting " submitted by Mr. DURGESH R. THUMAR [180044006] studying at Mechanical Engineering Department. Faculty of Engineering & Technology, for the award of M.Tech Mechanical-Production engineering is absolutely based on his own work carried out under my supervision and that this work/thesis has not been submitted elsewhere for any degree/diploma. Date – Place - ______________________ ______________________ Dr.G.D.Acharya Mr.Manojkumar.V.Sheladiya Principal, Head of Mechanical AITS Rajkot Engineering Department Seal of Institute

INDUSTRY CERTIFICATE

COMPLIANCE CERTIFICATE It is certified that the work contained in this dissertation thesis entitled "Investigation on the effect of alloying elements addition and solidification time on nodularity on 400/15 SGI casting" submitted by Mr. DURGESH R. THUMAR [180044006] studying at Mechanical Engineering Department, Faculty of Engineering & Technology for partial fulfillment of M.Tech degree to be awarded by ATMIYA University. He has complied the comments of the Dissertation Progress Review-I, Dissertation Part-I as well as Dissertation Progress Review-II with my satisfaction. Date: Place: ______________________ ______________________ Durgesh R. Thumar Mr. manojkumar v. Sheladiya (180044006) head of department Principal AU Rajkot

THESIS APPROVAL CERTIFICATE It is certified that the work contained in this dissertation thesis entitled "Investigation on the effect of alloying elements addition and solidification time on nodularity on 400/15 SGI casting" submitted by Mr. DURGESH R. THUMAR [180044006] studying at Mechanical Engineering Department, Faculty of Engineering & Technology for partial fulfillment of M.Tech degree to be awarded by ATMIYA University. Date: Place: External Examiners Sign and Name: 1) 2)

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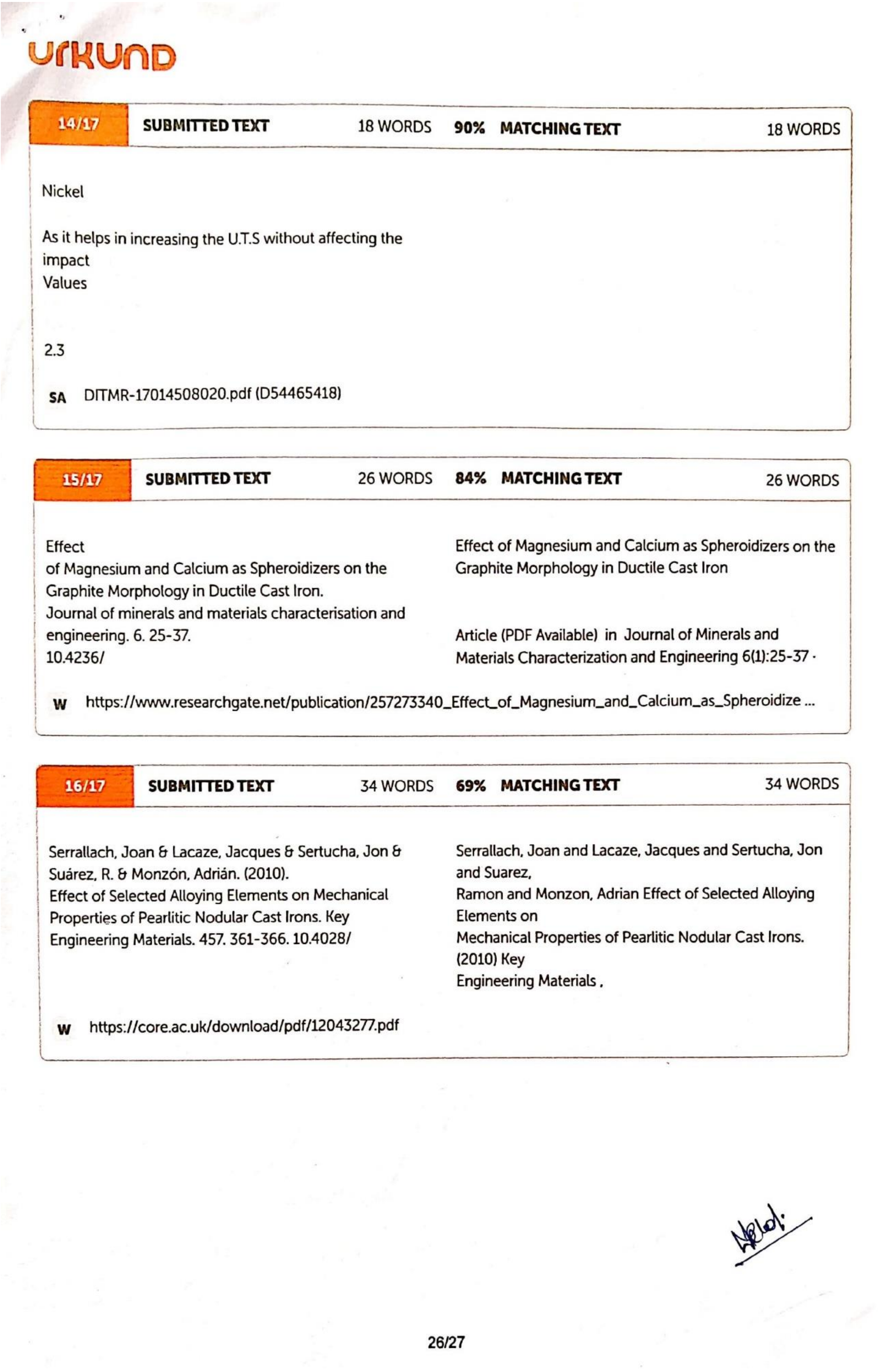

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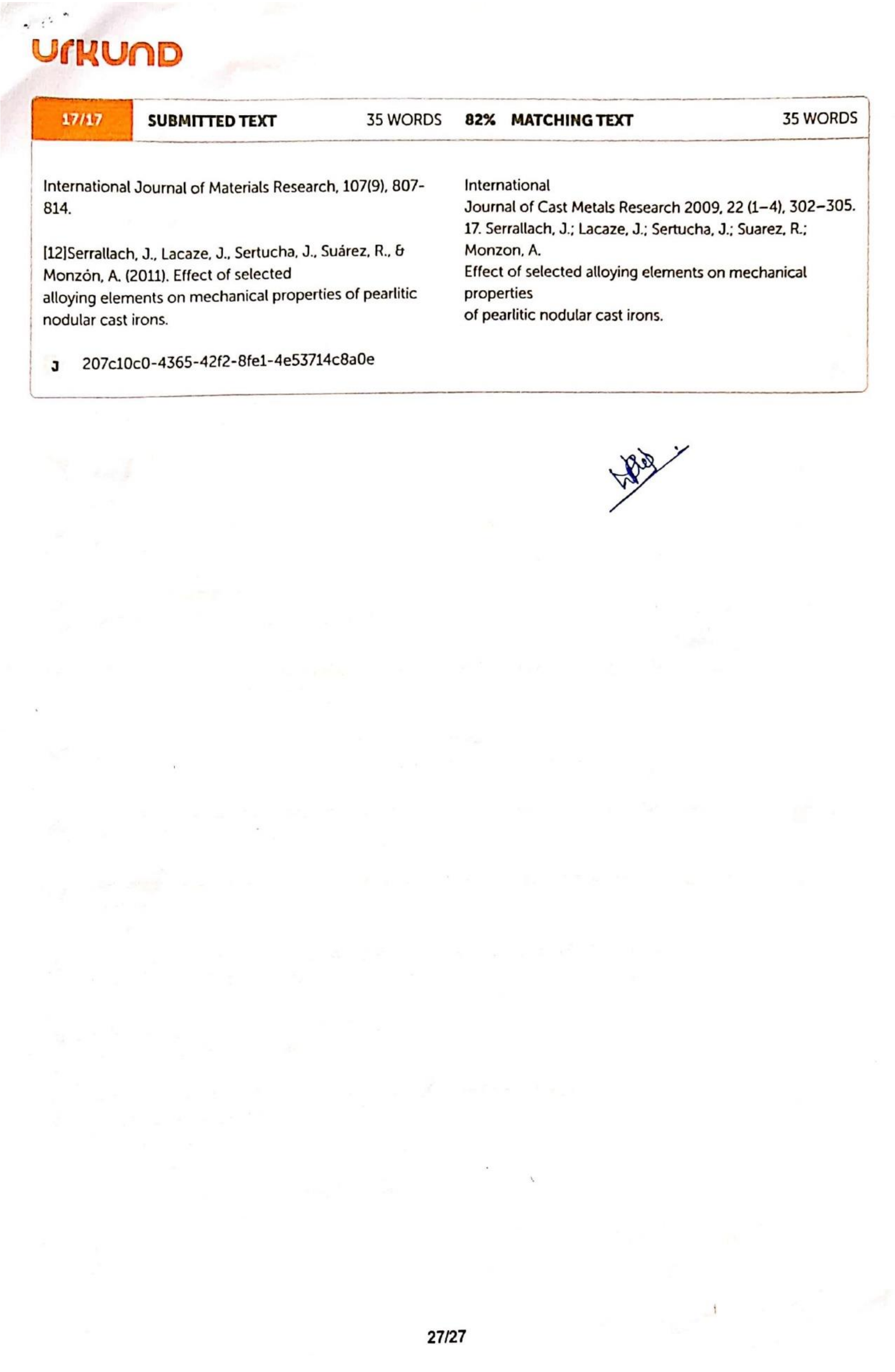

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	International Journal of Materials Research, 107(9), 807-814. [12]Serrallach, J., Lacaze, J., Sertucha, J., Suárez, R., & Monzón, A. (2011). Effect of selected alloying elements on mechanical properties of pearlitic nodular cast irons.	International Journal of Cast Metals Research 2009, 22 (1–4), 302–305. 17. Serrallach, J.; Lacaze, J.; Sertucha, J.; Suarez, R.; Monzon, A. Effect of selected alloying elements on mechanical properties of pearlitic nodular cast irons.

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