Examining material properties of the metal with probable values calculated from the grayscale image.

By

Nirajkumar Patel

Thesis

Submitted to Flinders University

for the degree of

Master of Engineering (Mechanical)

College of Science and Engineering

12/10/2023

TABLE OF CONTENTS

ABSTRACT

This research explores the possibility of accurately determining the material properties of metals from grayscale images. The primary objective is to identify suitable material for this investigation. To achieve this goal, tensile testing and hardness testing are performed with specimens prepared from ASTM A 516 Grade 70 steel using a standard design and waterjet cutting technology. Some specimens were subjected to sandblasting, introducing controlled corrosion. Grayscale images were collected both before and after heat treatment processes, and their results were correlated with experimental data. X-ray imaging was conducted at 120 kV with 8 mA and 90 kV with 4 mA power, with a flash distance of 100cm. The heat treatment processes, including annealing at 700°C, normalising at 900°C, and quenching in water at 900°C, were applied to the tensile and hardness specimens. Subsequent X-ray imaging was performed to detect changes in material properties following the heat treatment. Round samples were tested for Vickers hardness with a 3-gram force, and a 50kN-capacity Instron machine was used for tensile testing to find out the Young's modulus. Microscopic examinations revealed the heat treatment results, and SEM (scanning electron microscope) analysis was employed to study grain structures. Ultimately, this research determines that, while MATLAB code can extract magnitude, density, and pixel values from X-ray images, it is not possible to accurately predict the material properties of metal solely based on these variables. The study confirms the success of the heat treatment processes, providing valuable insights into the limitations of image-based material property assessments.

Keywords: Grayscale Image, X ray images, Tensile testing, Heat treatment process, Hardness Testing.

DECLARATION

I certify that this thesis:

1. does not incorporate without acknowledgment any material previously submitted for a degree or diploma in any university
2. and the research within will not be submitted for any other future degree or diploma without the permission of Flinders University; and
3. to the best of my knowledge and belief, does not contain any material previously published or written by another person except where due reference is made in the text.

Signature of student : Niraj

Print name of student: - Nirajkumar Jagdishbhai Patel

Date : 12/10/2023

I certify that I have read this thesis. In my opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Master of Engineering (Mechanical). Furthermore, I confirm that I have provided feedback on this thesis and the student has implemented it fully.

Signature of Principal Supervisor : Stuart Wildy Digitally signed by Stuart Wildy
Date: 2023.10.16 15:41:48 +10'30'

Print name of Principal Supervisor : Dr Stuart Widly

Date: 12/10/2023

ACKNOWLEDGEMENTS

I am deeply grateful for the unwavering support and invaluable guidance provided by the individuals who have played pivotal roles in the successful completion of this project. Their contributions have not only enhanced my skills but have also bolstered my confidence as an engineer. Their motivation and support have been instrumental in my journey of growth and learning, both within the academic realm and in real-world industries.

First and foremost, I extend my heartfelt appreciation to Dr. Stuart Wildy, my esteemed supervisor throughout the duration of this project. Dr. Wildy's mentorship has been nothing short of extraordinary. His expertise, dedication, and unwavering encouragement have been the cornerstones of my professional development. His motivation not only fuelled my passion for learning but also instilled in me a sense of self-motivation that drove me to give my very best to this project.

I would also like to express my sincere gratitude to Mr. Tim Hodge, a distinguished member of the engineering service team at Flinders University. Under Mr. Hodge's expert guidance, I had the privilege of conducting numerous experiments at the university. His vast knowledge of the latest technologies, particularly in the realm of let-test technology, has served as a constant source of inspiration for me to delve into new machines and technologies both in the academic setting and in real industries.

My appreciation extends to Mr. Bruce, a dedicated sales executive at Ferrcut, for his instrumental role in helping me gain crucial insights into the workings of real industries. Mr. Bruce's support in providing industry-specific materials and facilitating their timely deliveries has been indispensable to the progress of my project.

I am equally indebted to Mr. Chris, the proprietor of CNC cutting services, who generously afforded me the opportunity to prepare my samples for testing. His unfaltering support throughout the project has been of immense value to our entire team, and I am deeply thankful for his contributions.

Lastly, but certainly not least, I would like to extend my gratitude to all my professors who have directly or indirectly influenced and guided me during this project. Their collective wisdom and encouragement have left an indelible mark on this chapter of my life, and I will forever cherish the knowledge and experiences gained with their guidance.

This project has been a journey of growth, learning, and collaboration, and it wouldn't have been possible without the support and expertise of these exceptional individuals. I sincerely thank each and every one of them for their unwavering support and encouragement.

LIST OF FIGURES

LIST OF TABLES

1. Introduction

The introduction introduces the primary research objective: the investigation of determining the material properties of metals from grayscale images, with a special focus on employing MATLAB examination for the analysis of X-ray images. This research has wide-reaching implications for applications in engineering and manufacturing. The main goal of this project is to find the material properties of the metal using X-ray images (grayscale images). X-ray images have pixel values, and this research is centred around the analysis of these pixel values and their correlation with the actual material properties of the metal. It explores two key approaches: experimental material properties and theoretical material properties. The experimental methodology involves the utilisation of advanced technology available at the institution, such as X-ray, Instron machine, hardness testing machine, Muffle furnace and SEM (Scanning Electron Microscopy) Machine. High-quality metal samples obtained from Australian industries, specifically ferrocut, have been painstakingly prepared for tensile and hardness testing. The specimen designs have been carefully crafted to ensure precision, and the use of a water jet cutting method has been chosen to minimise heat-induced alterations. Providing vector file designs is crucial for precise machine interpretation. In total, the study has generated 20 tensile and 16 hardness testing samples. This research, which combines grayscale image analysis and MATLAB examination, has the potential to redefine how we approach material characterization and mechanical property assessment in the future.

1.1. Overview of the Literature

With its many applications, including CT, radiography, angiography, surgery, and mammography, X-ray imaging is essential to the medical field in meeting a variety of imaging needs. X-ray technology is a crucial component of modern healthcare because these systems have been created to support medical procedures and be used for diagnostic purposes. (Spahn, 2013).X-ray technology is an essential tool for studying the properties of bone. It provides important information on the structure of bone, including its hierarchical structure and its response to radiation. This information helps us understand the mechanical properties and behaviour of bone. (Barth, 2011). X-ray technology is widely used in non-destructive testing (NDT) to investigate and identify cracks in several materials, including composites and metals. The material can be investigated with X-rays without destroying the tested objects in order to identify any hidden errors, defects, or structural weaknesses. In industries which include aircraft, manufacturing, and construction, this technique provides a non-invasive and very efficient way for maintaining the integrity and safety of essential parts. (Guo, July, 2018). With positive results for digital defect detection, this work presents a fuzzy theory-based technology for successful X-ray image filtering. It is especially helpful in locating microscopic fractures and blowholes. (Lashkia, 2001). With the goal of improving industrial product and weld inspections while maintaining production safety, this study explores the use of X-ray computed radiography (CR) as a viable technique for precisely measuring the thickness of metal parts. (Bayu, 2018)

1.2. Aim of this research

The aim of this research is to assess the feasibility of calculating the material properties of metals by analysing the grayscale contrast in x-ray images. This involves a comprehensive investigation, including the following objectives:

- Fabricate steel tensile test specimens with varying material properties through controlled heat treatment processes.
- Employ x-ray imaging techniques to examine the alterations in grayscale contrast within the images resulting from the changes in the material properties of the specimens.
- Conduct material testing experiments to quantify and comprehend the modifications in the material properties of the specimens under investigation.
- Perform an in-depth material examination to scrutinise the grain structure and composition of the materials in order to gain a comprehensive understanding of the underlying changes.
- Finally, analyse the acquired experimental data by establishing correlations between the alterations in material properties and the corresponding variations in grayscale contrast observed within the x-ray images.

The overarching goal of this research is to determine whether a relationship exists between material properties and the grayscale contrast in x-ray images, potentially offering a novel and non-destructive method for assessing the characteristics of metals.

1.3. Scope in the research

The scope of the research, aimed at addressing the question of whether the material properties of metals can be determined from the grayscale contrast of x-ray images, encompasses the following key elements:

- **Specimen Preparation**: The research involves the creation of steel tensile test specimens with intentionally varied material properties. This is achieved through the application of heat treatment processes, enabling the generation of specimens with distinct characteristics, such as varying levels of hardness, ductility, and microstructural features.
- **X-ray Imaging**: The project encompasses the use of x-ray imaging techniques to capture images of the fabricated specimens. These x-ray images serve as a primary data source for the investigation, and any changes in grayscale contrast within these images are of particular interest.
- **Material Testing**: In order to investigate alterations in material properties, a series of material testing experiments are carried out on the fabricated specimens. These tests provide quantitative data related to characteristics like tensile strength, yield strength, hardness, and other relevant material properties.
- **Material Examination**: A critical aspect of the research involves a detailed examination of the material's grain structure and composition. This examination seeks to understand the microstructural changes within the specimens and the effect of heat treatment on their internal characteristics.
- **Data Analysis**: The research culminates in the analysis of the collected experimental data. This analysis involves the correlation of observed changes in material properties with corresponding changes in the grayscale contrast within the x-ray images. Statistical and analytical techniques will be employed to discern patterns and relationships in the data.

The research is multifaceted, bridging the realms of material science, imaging technology, and data analysis. It seeks to explore the potential for non-destructive evaluation of material properties through x-ray imaging, which could have significant implications for various industrial and scientific applications.

2. Literature Review

2.1. Application of Heat treatment Process for steel Tensile Test.

Heat treatment procedures are used to improve the mechanical characteristics of steel and optimize its performance for specific applications. The process involves heating and cooling the metal in a controlled manner to alter its microstructure and properties. (Instructables, 2017). Different heat treatment techniques can be used to change the microstructure and enhance the material's strength, ductility, and toughness when preparing steel samples for tensile testing (Dhoska, 2019).

Annealing is a heat treatment process that involves heating the metal to a specific temperature and then cooling it slowly. This process helps to reduce the hardness of the metal, increase its ductility, and improve its machinability. (Shane., 2023)During annealing, steel is heated to a certain temperature and then gradually cooled to room temperature. This process lowers internal tensions, improves the microstructure, and makes the material more ductile. An annealing process is widely used to soften and homogenise cold-worked or cast steel samples before tensile testing. To achieve precise and trustworthy findings, annealing is frequently used before tensile testing. As it aids in restoring their mechanical qualities and gets the samples ready for future testing or processing, it is especially helpful for cold-worked or cast steel samples (Markötter, 2023). In general, annealing is essential for improving the performance of steel in a variety of applications.

Normalizing is another heat treatment technique that involves heating the metal to a specific temperature and then cooling it in air. This process helps to refine the grain structure of the metal, improve its mechanical properties, and reduce internal stresses. Normalizing is a heat treatment process that involves heating the steel to a specific temperature and then cooling it in air. This process helps to refine the grain structure of the steel, improve its mechanical properties, and reduce internal stresses. The process also increases the material’s toughness, homogeneity, and strength, making it more suited for tensile testing and other uses that call for good mechanical performance. (Shane., 2023)

(John, 2023) In order to increase the mechanical characteristics of steel and refine the grain structure, normalising is a heat treatment procedure. After being heated over its critical temperature, the steel is cooled by air. This procedure improves the material's toughness, homogeneity, and strength, making it more suited for tensile testing and other uses that call for good mechanical performance.

Quenching is a heat treatment process that involves heating the metal to a specific temperature and then cooling it rapidly in water or oil. This process helps to harden the metal by transforming its microstructure into martensite, which is a hard and brittle phase. (John, 2023). A two-step heat treatment procedure known as quenching and tempering is frequently used to maximise the strength and hardness of steel. To acquire high hardness, the steel is first heated to a high temperature and then quickly cooled (quenched) in a medium like oil or water. A hardened microstructure is produced in this process. However, the steel becomes very brittle and crack- prone. The hardened steel is then heated to a lower temperature and gently chilled (tempered) to regain some ductility and toughness. The steel is appropriate for tensile testing and applications where a balance of strength and ductility is required since the tempering process gives favourable mechanical qualities, such as improved toughness and reduced brittleness. (tec-science, 2023)

According to (Kafka, 2022), the goal of the heat treatment procedure known as "stress relief annealing" is to reduce any remaining tensions in the steel structure. Steel samples may encounter internal stresses during mechanical processes like welding, machining, or cold working that might impact how they behave during tensile testing. In order to alleviate these internal tensions, steel is heated to a certain temperature and then progressively cooled. Results from tensile testing may be more precisely and consistently obtained thanks to this procedure, which helps prevent deformation, cracking, or early failure.

Age hardening, commonly referred to as precipitation hardening, is a heat treatment method used for specific kinds of steel alloys. It entails a number of stages, including quenching, ageing, and solution treatment. The steel is heated during the solution treatment to dissolve any precipitates, and it is quickly cooled during the quenching to create a supersaturated solid solution. (Zhang H. P., 2022). In order to allow for the production of fine precipitates inside the microstructure, steel is reheated to a specified temperature and held there for a while throughout the ageing process. Steel's strength and hardness are greatly increased after precipitation hardening, making it ideal for applications requiring high tensile strength.

2.2. Preparation Using X ray Images investigation in Grayscale contrast

According to (Kaczmarczyk, 2022), stated that X-ray imaging is a useful technique to investigate variations in grayscale contrast and get knowledge about the interior structure and composition of materials. Researchers can learn vital details about the material qualities, flaws, and structural alterations by examining grayscale differences in X-ray pictures. The attenuation of X-ray radiation as it travels through an item is seen in X-ray pictures. Grayscale contrast in X-ray imaging relates to variations in X-ray transmission intensity and reveals variations in material composition, thickness, or density. Greater X-ray attenuation is represented in the grayscale picture by darker regions, while greater X-ray attenuation is represented by brighter parts. Experts can spot structural changes, flaws in materials by analysing grayscale fluctuations. The distribution, size, and density of features within the material are all useful information that may be learned by quantitative grayscale analysis. In order to help in quality control and comprehend the internal structure of materials, grayscale contrast in X-ray pictures enables non-destructive inspection and assessment of material attributes. (Barth, 2011)The investigation of structural changes in materials, such as phase transitions, grain expansion, or the existence of flaws, may be done using X-ray imaging. Researchers can spot variations in grayscale contrast that signify changes in the underlying structure of a material by comparing grayscale photographs of the same material before and after a procedure or treatment. These modifications might take the shape of new phases, variations in grain size, the development of fractures or voids, or the addition of alien particles (Wang Y. T., 2022)Experts may identify and characterize these structural alterations by examining the variations in grayscale contrast between the photos. Understanding the behaviour of the material, evaluating the efficacy of processing or treatment procedures, and guaranteeing the integrity and quality of the material for its intended purpose all depend on this knowledge. (Wang L. , 2022)

Quantifying the grayscale intensity distribution in X-ray pictures is the goal of grayscale analysis. The interior structure of the material may be quantitatively described by transforming the X-ray pictures to grayscale and examining pixel intensities. Different image processing methods, such as histogram analysis, thresholding, or edge detection algorithms, can be used to carry out this study. The characterization and comprehension of structural changes are aided by the useful information that grayscale analysis gives on the distribution, size, and density of features within the material. Grayscale contrast variations in X-ray pictures can be linked to certain material characteristics. Lower grayscale values, for instance, can indicate inclusions, thicker sections, or regions with greater densities. Higher grayscale values, on the other hand, can point to voids, porosity, or regions with reduced density. Researchers can deduce details about the material's composition, homogeneity, porosity levels, and possible flaws by examining these grayscale variations. (Kim, 2020). Grayscale contrast and material attributes are correlated, which enables non-destructive inspection and assessment of the material's quality and integrity. There are several sectors that use X-ray imaging with grayscale contrast analysis. It is used in materials research to examine the microstructure of alloys, composites, and ceramics, locating characteristics like phase distribution, grain boundaries, or intermetallic compounds. Using X-ray imaging, manufacturing professionals can find flaws in cast parts, welded connections, or additive manufacturing. X-ray imaging in medicine offers vital information about bone density, fractures, or foreign items within the body. Application of Material Testing to Investigate Changes in Material Properties According to (Kafka, 2022), Investigating changes in material characteristics is greatly aided by material testing, which also offers insightful information on how different materials behave and operate. Researchers may access and analyse changes in attributes including strength, hardness, ductility, and fatigue resistance by putting materials through controlled testing settings. Tensile testing is frequently used to assess a material's mechanical attributes, notably its strength and ductility. Researchers can test characteristics like yield strength, ultimate tensile strength, elongation, and elastic modulus by applying an axial pulling force to a material. Tensile testing aids in identifying changes in a material's qualities brought on by things like production procedures, heat treatments, or exposure to the environment. Researchers may analyse changes in the material's strength and ductility by comparing tensile test results before and after a treatment or procedure, giving them important insights into the material's structural behaviour. (Li, 2020). Testing for hardness entails determining a material's resistance to penetration or indentation. a number of factors, including the substance being tested and the goal of the measurement scale, multiple states hardness methodologies, which include Brinell, Rockwell, or Vickers, are used. Testing for toughness is frequently utilized for assessing how a material's hardness, durability against wear, and durability against fatigue have fluctuated over time. Scientists can assess variations in the material's surface & bulk hardness, revealing data concerning changes in the material's architecture or composition, through conducting hardness tests before and after certain procedures or processes.

2.3. Material Examination Process to Investigate Material grain structure and Composition.

The evaluation starts with a macroscopic investigation to look at the material's overall appearance. Surface flaws, fissures, or inclusions can be seen by visual inspection and low- magnification microscopy. The initial information regarding the material's overall state and any potential flaws that could influence further investigations is provided by this examination. Representative samples are made so that extensive microstructural examination may be done on them. To create a flat, mirror-like surface, the material must be cut, mounted, ground, and polished. The preparation guarantees correct sample representation and gets rid of any artefacts that can impede precise evaluation. One of the main methods for material investigation is optical microscopy. (Lu, 2020). An optical microscope is used to look at a polished sample, allowing for the observation of the material's microstructure and grain boundaries. The determination of grain size, grain shape, and general microstructural characteristics is possible with optical microscopy. Contrast enhancement can be done by etching the sample with certain chemicals, displaying grain boundaries more clearly. SEM enables fine-grained examination of the material's grain structure and offers high-resolution imaging of the material's surface. The secondary and backscattered electrons produced by the focussed electron beam in the SEM are employed to reveal topography and composition. Grain boundaries, surface flaws, the presence of precipitates, and foreign inclusions may all be seen using SEM investigation. Furthermore, an energy-dispersive X-ray spectroscopy (EDS) connected to the SEM may be employed for identifying the fundamental makeup of specific regions or patterns within the substance being studied. X-ray diffractometry (XRD) is a technique for evaluating the crystallography chemical makeup of materials. In order to accomplish this, an investigator needs an X-ray substrate to measure and study the reflected X-ray spectra. (Lopresti, 2020). XRD can determine the crystal structure, phase composition, and orientation of grains as well as the arrangement of atoms inside the material.

(Xu, 2020)A strong method for mapping the crystallographic orientations and grain boundaries within a material is EBSD. Backscattered electrons are collected using an electron beam and a specialised detector. EBSD offers thorough details regarding crystallographic orientation, grain size, and grain boundary properties by examining the patterns of backscattered electrons. The grain structure of the material may be quantitatively analysed because to EBSD's ability to provide orientation maps, misorientation angles, and grain boundary distributions. The surface chemistry and elemental makeup of the material can be ascertained using AES or XPS methods. In order to determine the elemental composition and chemical states present on the material's surface, these techniques examine the energy and intensity of radiated electrons or X-rays. When it comes to surface pollutants, oxide coatings, or changes in elemental composition brought on by procedures like oxidation or surface treatments, AES and XPS can offer useful information. (Xu, 2020).Data using microscopy techniques are processed and evaluated using sophisticated microstructural examination tools. Without the assistance of this program, it is feasible to analyse photographs, determine the grain size, identify steps, and take qualitative measurements of different microstructural features. The results of these studies offer statistical data on the geographic distribution of the sizes of grains, phase fractions, and various other important microstructural features.

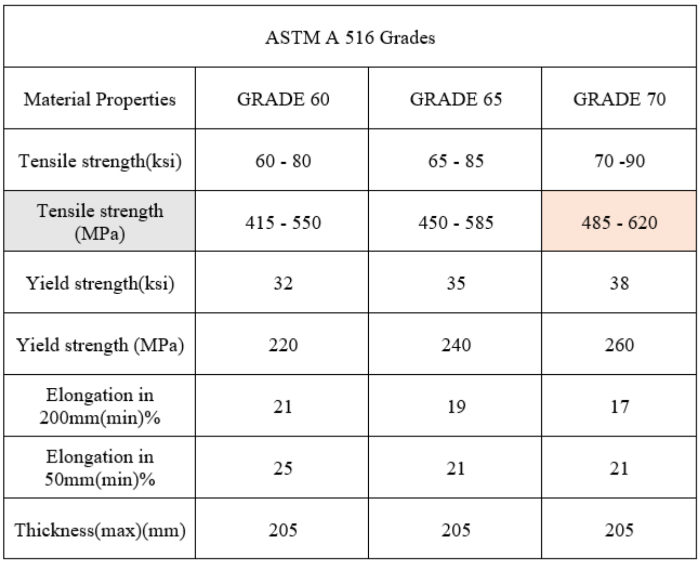
2.4. Literature gap

There is a void in the literature about the thorough investigation of steel material characteristics using x-ray imaging, grayscale analysis, and tensile testing all at once. While individual studies have looked into each technique separately, there is a lack of research that combines these approaches to give a comprehensive understanding of the relationships between microstructural features seen in x-ray images, grayscale variations, and the resulting mechanical properties. Strong relationships between the grayscale contrast seen in X-ray pictures and certain mechanical characteristics of steel, such as yield strength, ultimate tensile strength, and ductility, need to be established via more study. Professors can gain a better understanding of the underlying microstructural changes that affect material qualities by statistically analysing grayscale variations and their connection to mechanical behaviour (Zhang et al., 2019). By combining the use of x-ray imaging, grayscale analysis, and tensile testing, knowledge gaps in the literature will be filled and the characteristics of steel materials will be better understood. It will help to the improvement of characterisation methods for steel materials and offer insightful information about the microstructural alterations that affect mechanical behaviour.

3. Methodology

3.1. Material Selection

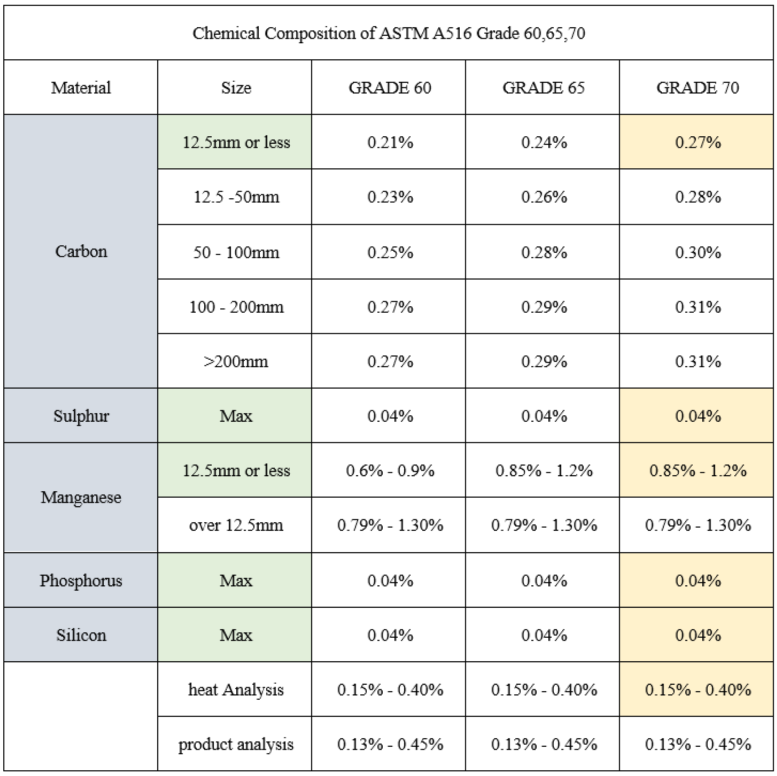
In selecting the most appropriate material for this research, the material properties of ASTM A516 Grades 60, 65, and 70 play a crucial role, as outlined in Table 1, which explains the different grades and material properties of the carbon steel ASTM A516 material. Among these grades, ASTM A516 Grade 70 stands out as the preferred choice for this investigation due to its specific material attributes. It offers a tensile strength ranging from 70 to 90 ksi (485–620 MPa) and a yield strength of 38 ksi (260 MPa), making it a robust and versatile option for our research, particularly when applied to pressure vessel applications. With an elongation of 17% in 200mm and 21% in 50mm, it can accommodate specific design requirements while ensuring optimal performance in challenging conditions. Additionally, the maximum thickness of 205 mm aligns well with the parameters of our study, which focuses on material characterization using X-ray images.(Table is mentioned in appendix)



ASTM A 516 Grades			
Material Properties	GRADE 60	GRADE 65	GRADE 70
Tensile strength(ksi)	60 - 80	65 - 85	70 -90
Tensile strength (MPa)	415 - 550	450 - 585	485 - 620
Yield strength(ksi)	32	35	38
Yield strength (MPa)	220	240	260
Elongation in 200mm(min)%	21	19	17
Elongation in 50mm(min)%	25	21	21
Thickness(max)(mm)	205	205	205

Table 1 Material Selection (ASTM A 516grades)

Chemical compassion of steel ASTM A 516 grade 70 is explained in table 2. This table provides detailed insight into the material's composition. ASTM A516 Grade 70 is characterised by a specific chemical composition. It contains 0.27% carbon (C), with controlled levels of other elements, including 0.04% sulphur (S), 0.85% to 1.2% manganese (Mn), 0.04% phosphorus (P), and 0.04% silicon (Si). This chemical makeup is a critical factor in the material's suitability for various applications, particularly in industries where precise material properties are essential for ensuring safety and structural integrity. The controlled content of these elements is carefully regulated to meet the required standards and performance expectations. (Table are mentioned in appendix)



Chemical Composition of ASTM A516 Grade 60,65,70				
Material	Size	GRADE 60	GRADE 65	GRADE 70
Carbon	12.5mm or less	0.21%	0.24%	0.27%
	12.5 -50mm	0.23%	0.26%	0.28%
	50 - 100mm	0.25%	0.28%	0.30%
	100 - 200mm	0.27%	0.29%	0.31%
	>200mm	0.27%	0.29%	0.31%
Sulphur	Max	0.04%	0.04%	0.04%
Manganese	12.5mm or less	0.6% - 0.9%	0.85% - 1.2%	0.85% - 1.2%
	over 12.5mm	0.79% - 1.30%	0.79% - 1.30%	0.79% - 1.30%
Phosphorus	Max	0.04%	0.04%	0.04%
Silicon	Max	0.04%	0.04%	0.04%
	heat Analysis	0.15% - 0.40%	0.15% - 0.40%	0.15% - 0.40%
	product analysis	0.13% - 0.45%	0.13% - 0.45%	0.13% - 0.45%

Table 2: Final materials selection ASTM A516 grade 70

3.2. Test specimen Preparation

Tensile testing samples: An essential part of this project is the preparation of the samples. Tensile testing is the best method for determining the material's Young's modulus. Based on the Instron test specimen standard, the research requires a dog bone test specimen design. The optimal dog bone measurements for this study are 5 mm for thickness, 200 mm for length, and 12 mm for width in the middle. But after getting in touch with several businesses, including Ferrocut, Apex Steel, Australian Steel, and Steel Plus, it was discovered that none of them produced sheets with a thickness of 5 mm. They all use ASTM A516 A-grade 70 material instead, and each one produces sheets that are 6 mm thick. Accordingly, the dimensions were changed to satisfy the research needs and satisfy industry standards. ASTM A516 grade 70, 6 mm thick, is the material used for this project. The company Ferrocut Industries provided the best estimate and the right size for this project, thus it was bought from them. The engineering service guidelines and experience were used to modify the tensile testing sample's dimensions.

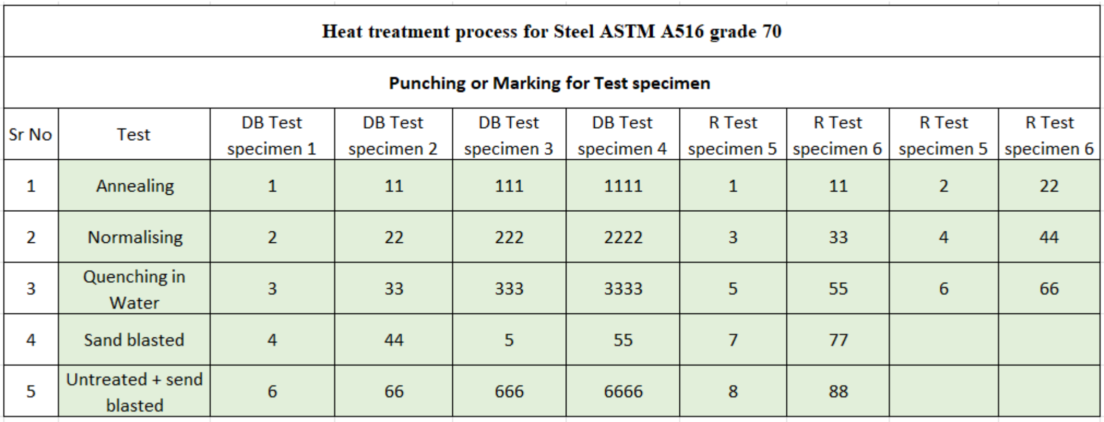
Hardness testing Samples: As an alternative, the test specimen's hardness value can be obtained by the researchers. A 25 mm hardness sample would be a good diameter in this case. The test specimen's diameter can be reduced, and researchers can use resin to make a new mounting base. It was ultimately chosen to use this dimension since it is appropriate for this project, even though the polishing machine's mounting port has a conventional diameter of 25 mm.

The most difficult aspect of sample preparation is determining how much of the test specimen to use. There are two choices for sample preparation in this research: The first approach is to gather the data from the various heat treatment procedures using one sample for each technique. Another choice would be to get more samples prepared for various heat treatment procedures. In this study, four samples are used for each treatment to gather data from in case one sample fails to provide accurate results. Once the sample results have been gathered, the average of each result can be used to provide sample results that are more accurate. The pressure utilised in water jet cutting machines normally ranges from 30,000 psi (210 MPa) to 90,000 psi (620 MPa). All samples are prepared on these machines. A water jet cutting machine's ideal pressure varies depending on several variables and system to system. Operating pressures can vary, with some systems performing optimally at 40,000 psi and others at 55,000 psi. 16 samples for hardness (round) and 20 samples for tensile testing (dog bone) have been generated by a water jet cutting machine.

Samples are prepared at CNC cutting services at Water jet cutting machine, and prepared samples by machine, which are mentioned in figure 1. (Detailed image is mentioned in appendix). All the samples are prepared by a water jet cutting machine; however, because of the chemical reaction that happens between steel and water, several of the samples have corrosion problems. To solve this problem, the edges, and surfaces of half of the samples had been coated to prevent corrosion by sandblasting. In this investigation, a numerical punching method has been used to identify every sample. The test specimen identification is explained in the table below. The samples were immediately permanently marked with a hammer and a numerical punch after having been placed on an anvil.

Figure 1 Water Jet Cutting machine and prepared sample by CNC Cutting services.

To understand the test specimen number and the whole treatment, Table 3 will give a clear idea of the test specimen. Here is a total of five treatments: annealing, normalizing, quenching in water, sand blasting, and untreated samples. Each treatment has 4 tensile test specimens and 4 hardness test specimens. Each treatment has 2 sand-blasted samples and 2 untreated samples. For example, the annealing heat treatment process has a total of 8 test specimens, of which 4 are tensile testing and 4 are hardness testing. For tensile testing, test specimen (dog bone shape) number 1 and test specimen number 11 are sandblasted, while samples 111 and 1111 are untreated. For hardness testing (round shape), test specimens 1 and 11 are sandblasted, and test specimens 2 and 22 are untreated. That means each testing method can give two different types of results.



Heat treatment process for Steel ASTM A516 grade 70

Punching or Marking for Test specimen

Sr No	Test	DB Test specimen 1	DB Test specimen 2	DB Test specimen 3	DB Test specimen 4	R Test specimen 5	R Test specimen 6	R Test specimen 5	R Test specimen 6
1	Annealing	1	11	111	1111	1	11	2	22
2	Normalising	2	22	222	2222	3	33	4	44
3	Quenching in Water	3	33	333	3333	5	55	6	66
4	Sand blasted	4	44	5	55	7	77		
5	Untreated + send blasted	6	66	666	6666	8	88		

Table 3: Marking on each test specimen.

3.3. X ray images before heat treatment process

This study uses X-ray imaging as an important aspect, and the modern X-ray machine at Flinders University—which is typically used for medical purposes—is an effective instrument for materials characterization. The study's main goal is to gather

X-ray data from meticulously manufactured test specimens. In order to ensure that the samples were oriented perpendicularly to the X-ray beams and enable radiation to pass through the specimens, a precise spacing of 100 cm was kept between the test specimen and the X-ray flash point. This approach is closely related to the general research objectives and revolves on the measurement of material thickness. A set of four samples, two sandblasted and two untreated, were used for each treatment process. The specimens data were collected in this research using an x-ray machine operating at 120 KV with 8 ma power and a flashing distance is 100 cm. Results were initially combined into a single set within the treated samples; however, a numerical identification method was carefully developed for the software to reduce the difficulty of understanding individual X-ray images within the software because the images had no numerical markers. This made image recognition by sample easier. Notably, the data is stored in the very specialised DICOM file format, which makes it difficult to understand on older devices. The research uses the DICOM sonic reader, a specialised technology that makes it possible to interpret these images on a number of devices, to get around this problem. Moreover, the software makes use of the capacity to easily translate DICOM images into the popular JPG format. In addition to being visually represented, these X-ray images give important density and pixel values since they include with quantitative data. This abundance of data is an essential resource for those seeking to comprehend material properties and the insights provided by X-ray imaging on a deeper level. Figure 3 explains how X – ray images are taken in the X – Ray machine and after numerical marking in the software.

Figure 2 : X ray images in the machine and Software.

3.4. Heat Treatment Process

Figure 4 explains TTT (Time, Temperature, and Transformation) diagram. TTT diagrams provides a clear visual representation of the complicated relationship between phases and material microstructure in setting of heat treatment procedures. Alpha (α), beta (β), and gamma (γ) are the three main phases that are pursued in the search for unique material features. To obtain a coarse perlite grain structure, annealing heat treatment is the objective. The alpha phase, identified by a ferrite and cementite mixture, is brought about by the heating phase at 700 °C and opens the door for later microstructural modifications. A fine pearlite grain structure is the goal of normalising, on the other hand. Start of the journey: at 900 °C, the alpha phase; austenite-characterized gamma phase comes. The resulting phase of normal temperature cooling develops the fine pearlite microstructure that is required. The alpha phase appears at the first heating at 900 °C in the context of quenching in water heat treatment; however, the fast quenching in water defines this method. Because of the rapid cooling, the material is stabilised in the martensite phase, which is recognised for its remarkable strength and hardness, and the transformation into other phases is delayed. By allowing materials to show a range of mechanical properties, from coarse perlite to fine pearlite and martensite, these phases—dynamically interacting against the backdrop of TTT diagrams—underpin the art and science of heat treatment and open up fresh possibilities for material engineering. The heat treatment process is the best way to modify the material's properties. To change the material properties of the metal, we are going to perform annealing, normalising, and quenching in the water heat treatment process on different test specimens. This all-heat treatment process is performed on the SEM 102C Muffle Furnace, which has a 3.5L capacity and heats to a temperature of 1100 °C. In this project, samples are prepared by annealing, normalising, and quenching in the water heat treatment process in the muffle furnace. The annealing heat treatment process is performed at Flinders University under the guidance of Flinders University engineering services. Before going to perform, it is very important to understand the TTT (time, temperature, and transformation) diagram. All temperatures are found with the help of the TTT (time, temperature, and transformation) diagram. With the help of this diagram, we can easily identify at which level we need to provide heat to the test specimen and which cooling method we can use to get the desired results after the experiment. Each heat treatment process uses 4 dog bone (2 untreated and 2 sandblasted) test specimens and 4 round (2 untreated and 2 sandblasted) test specimens to get the desired results. (Detailed TTT diagram is mentioned in appendix).

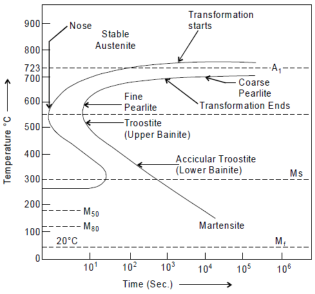


Figure 3: TTT (Time. Temperature, Transformation) Diagram.

3.5. X ray images after heat treatment process

After heat treatment process, X-ray results are obtained from the X-ray machine, as mentioned in figure 5. Throughout the course of the investigation, obtaining X-ray data took on an important function—both before and after applying of heat treatment procedures. We collected X-ray data with precision before having applied the transformational heat treatment processes for the test specimens. The use of a marking technique verified specimen identification accuracy and allowed for the simple tracking of the same samples over the period of the experiment. This consistency made it easier to compare data that had been collected under the same conditions straight. Maintaining a constant 100-cm flashing distance between the test specimen and the flash point was a standard setting for the X-ray data collection process. Comprehensive data collecting was made possible by the use of two different voltage and current settings: 120 kV with 8 mA power and 90 kV with 4 mA power. Furthermore, the waste part of the test specimen was carefully included into the imaging process to reduce the impact of edge effects in the X-ray images.

Figure 4 After heat treatment X ray result collection.

3.6. Hardness Testing

In many quality control and research and development processes, hardness testing is an essential component to find strength, ductility, and wear resistance. There are different types of hardness methods available in the world. Vickers, Knoop, Brinell, Rockwell, and shore scleroscope are a few popular hardness tests. Flinders University has developed a technology called Vickers's hardness testing machine, which is used in this research to collect the hardness values of the material. Before performing hardness testing, I tried to collect the grain structure with the help of microscopic examination on the test specimen. There is a problem in identifying the grain structure in the test specimens because some samples are sandblasted, and some samples are untreated. After changing material properties, samples need to be surface polished. With the help of the struers Tegramin 25 machine, some hardness samples (round shape) are prepared, and mirror polished. After changing the heat treatment process, all samples are very hard to polish. In the hardness testing, 3 grammes of force are applied to each specimen. The results are collected from 16 test specimens, which include annealing (4 round-shaped test specimens), normalising (4 round-shaped test specimens), quenching in water (4 round-shaped test specimens), and untreated (4 round-shaped test specimens).

3.7. Microscopic Examination (Microscope and SEM)

The collecting of microscopic results became easier after specimen polishing. Evaluation of the specimen's microstructure following heat treatment was the primary objective. Detailed grain structures were not possible to image in the first investigations, which were performed at a maximum magnification of 50X. Figure 6 explaining the samples in SEM machine.

Figure 5: Samples in SEM (Scanning Electron Microscopy).

In order to get around this, we used the highly advanced Scanning Electron Microscopy (SEM) equipment at Flinders University, which has an incredible 10,000X magnification. The SEM devices, which used electron beams and zero-space gravity, allowed for in-depth material examinations, which improved our comprehension of the specimen's microstructure. Furthermore, we used Energy Dispersive X-ray Spectroscopy (EDX) to verify post-heat treatment changes in components and properties. This integrated strategy improved the standard of our research by providing comprehensive knowledge into material changes as well as microstructure.

3.8. Tensile Testing

Tensile testing has been selected as the main method for gathering important material parameters in this study, such as Young's modulus (Modulus of Elasticity). Also use specific software to record a variety of important data, including stress-strain profiles, maximum and failure loads, Young's Modulus, and other material properties. It achieve this by using the Instron 5969 machine, which has a 50kN capability for applying tensile or compressive pressures. The software continuously tracks the specimen's behaviour and issues an alert when it is about to fail, while an extensometer helps hold the test specimen in place within the machine's gripper. The specimen is subjected to increasing loads until it fails before the extensometer is removed, and implanted sensors thoroughly record all relevant parameters. The foundation of working is this rigorous testing approach, which yields a thorough knowledge of material properties, especially Young's modulus.

3.9. MATLAB Examination

One of the main challenges in this research is calculating material properties from grayscale photographs, which is an extremely significant task. The DICOM file format presents challenges for traditional software to read the X-ray pictures because it is a complicated format. MATLAB proves to be a helpful partner in this situation, providing an answer to this problem. Developing a MATLAB algorithm that can effectively analyse DICOM images taken up a large amount of the team's effort and required a lot of time and resources. After much effort, a MATLAB code was successfully created, which made the process of reading images easier.

The X-ray pictures in question include key pixel values, which are a wealth of data. These pixel data are utilised by MATLAB, which transforms them into density and magnitude values, giving us access to an important analysis resource. These pixel and density values are critical to determining mean values from specific areas of interest. The same regions are examined using MATLAB to determine the mean pixel values in the context of tensile testing, where the test specimens experience a transformative rupture. The relevance of these average pixel values goes above the possible association with the outcomes of tensile or hardness tests, providing a comprehensive method for comprehending and evaluating material characteristics within the scope of our investigation.

4. Results

Results are a crucial part of this project. In this section, all results are mentioned after performing all experiments on all test specimens. The main aim is to collect results to fulfill the goal of this project. Test specimen preparation, heat treatment process, X-ray, hardness testing, microscopic examinations, tensile testing, and MATLAB examination results are mentioned in this section. There are lots of results collected in this project, and it is very hard to explain all the results in these sections, so the explained results are the mean results of each experiment. All results are mentioned in the appendix. Finally, all the results from the different experiments are compared with each other to achieve the goal of this project.

4.1. Sample preparations

Sample preparation is the beginning of this project. First of all, material selection was an important part of the sample preparation. The selected material for this project is carbon steel, ASTM A516 grade 70. Based on the requirements of the testing, the specimen is designed according to the standards of the testing aspects. A water jet cutting machine and sandblasting machine were identified for sample preparation, and after preparing samples based on Table 3, each sample is marked for sample identification. The final prepared samples are mentioned in Figure 9.

4.1.1. Tensile testing (Dog bone test specimen)

Tensile testing (Dog bone shape) specimen have been shown in the figure 7. The tensile test specimen dimension is prepared as per the Instorn machine standard.

Based on that standard, 5 mm-thick material is suitable for this research. As per market research, it is very hard to find the 5 mm in ASTM A516 grade 70. As a result, 6 mm of material thickness was used to prepare this test specimen for this project. A total of 20 tensile (dogbone) test specimens were prepared with the help of a water jet cutting machine. Some samples need edge preparation because all samples are prepared in one cut. Some samples have sharp edges, which can pose hazards, but after edge preparation, they are reduced.

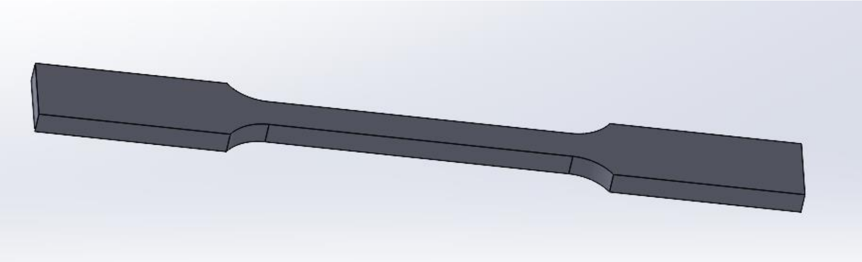


Figure 6: Tensile testing (Dog bone) test specimen Design.

4.1.2. Hardness Testing (Round test specimen)

Hardness test specimen design as shown in figure 8. Hardness test specimens are also prepared in the water jet cutting machine. In this research, more than one sample is used to collect the results. There are 16 samples prepared to collect the different heat treatment results. Edge preparation is done on each sample after water jet cutting.

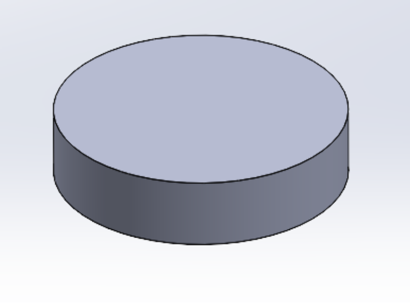


Figure 7: Hardness (Round) test specimen Dimentions.

The samples prepared for this study are detailed in Figure 9. Each sample is distinctly marked with a punch, in accordance with Table 3. Notably, a subset of these samples has been subjected to a sandblasting treatment, while others have remained untreated. Within Figure 9, you will find a comprehensive depiction of all the sandblasted samples. However, regrettably, the figure lacks an illustration of the untreated sample. This omission is due to my oversight during the research process, as it was inadvertently omitted. Nonetheless, the punch markings on the samples remain readily discernible, especially during hardness testing.

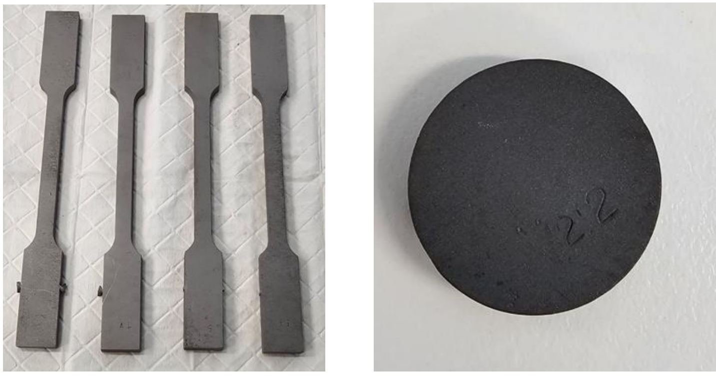


Figure 8: Prepared samples for testing.

4.2. Heat Treatment Process

The heat treatment process is used in this project to modify the material properties of the metal. In this project, a couple of heat treatment processes are performed on test specimens, which are annealing, normalizing, and quenching in water. Each heat treatment process is performed on a tensile test specimen and a hardness test specimen. In the below sections of this report, the heat treatment process that was performed is described. (All results and images are mentioned in the appendix).

4.2.1. Annealing Heat treatment Process

Annealing heat treatment process in the furnace and after cooling in the furnace images are mentioned in figure 10. In this work, a carefully supervised heat treatment procedure is carried out using techniques obtained from time-temperature transformation (TTT) diagrams. The primary objective is to cause the test specimens to undergo a particular microstructural modification, specifically a coarse perlite grain structure. The specimens initially heated to a temperature approximately to the recrystallization point, which is precisely 700°C, and are kept there for 15 minutes. The desired microstructural result is expected to be produced by this carefully controlled temperature and time setting. After heating, one of the most important steps in the process involves allowing the furnace cool down gradually for a whole day. The research goals are exactly matched with the specimens' final microstructure, which is shaped in large part by this cooling phase. 8 samples are cautiously handled in order to allow a thorough evaluation: 4 have been set separately for tensile testing and 4 for hardness testing. In the tensile testing group, researchers separate the untreated and sandblasted samples from table 3, which are clearly marked 1, 11, 111, and 1111; in the hardness testing group, samples 1 and 22 are included; samples 2 and 22 remain untreated, while samples 1 and 11 received sandblasting. This methodical approach provides that the heat treatment procedure is carried out precisely, adhering to the rules of the TTT diagram and providing the groundwork for a thorough material investigation and property evaluation in our study project.

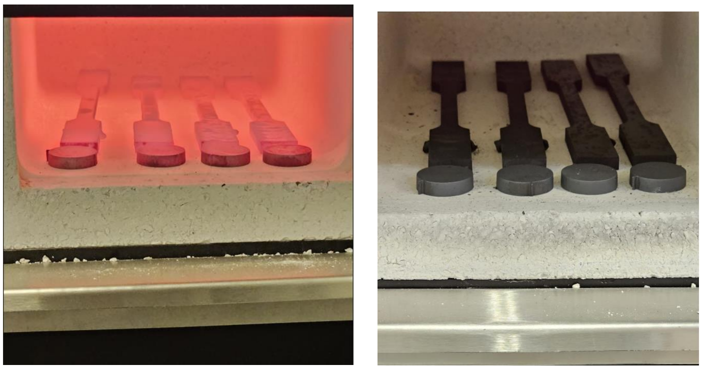


Figure 9: Annealing heat treatment process in furnace, and final results of the test specimen.

4.2.2. Normalising Heat treatment Process

Normalising heat treatment process in the furnace and after heat treatment process final image are mentioned in the figure 11. In this heat treatment process, the provided heat heats the test specimen to the nearest recrystallization temperature and cools it down to the normal atmospheric temperature. Based on the TTT diagram, the expectations are to get the fine pearlite grain structure from the test specimen. The provided heat for the test specimen is 900 °C at 20 minutes in the furnace to get the desired results. The cooling time at the normal temperature is 6 hours. This heat treatment procedure is applied to a total of 8 samples: 4 samples for tensile testing and 4 samples for hardness testing. During the normalising heat treatment procedure, two untreated samples and two sandblasted samples are prepared for tensile testing. In other words, based on table 3 tensile testing samples are 2, 22, 222, and 2222. Samples 2 and 22 have undergone sandblasting, whereas samples 222 and 2222 remain untreated. The hardness samples are 3, 33, 4, and 44 in order; in order to normalise heat treatment, 3 and 33 are subjected to sandblasting, while 4 and 44 are left untreated.

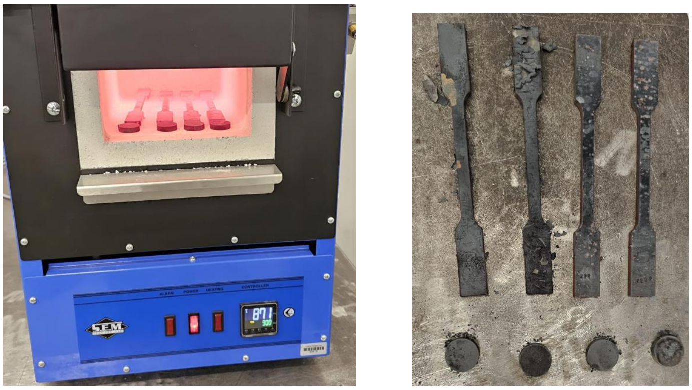


Figure 10: Normalising Heat treatment process in furnace and results on specimen.

4.2.3. Quenching in the water Heat treatment Process

Quenching in water heat treatment process in furnace and final results on samples are mentioned on figure 12. In this heat treatment process, we are providing heat to the test specimen to the nearest recrystallization temperature and instantly quenching it in the water. Based on the TTT diagram, we are expecting to get the martensite grain structure from the test specimen. The provided heat for the test specimen is 900 °C at 20 minutes in the furnace to get the desired results. All specimens are instantly quenched in the water. In 15 to 20 minutes, all test specimens are at normal temperature. After 15 to 20 minutes, all specimens are removed from the water to avoid corrosion. Total 8 samples are treated with this heat treatment method in total: 4 are used for tensile testing and 4 are used for hardness testing. Tensile tests are conducted on two untreated and two sandblasted samples that were created during the Quenching in water heat treatment process. The following are tensile test samples: 3,33,333,3333. Samples 33 and 3 have been sandblasted, but samples 333 and 3333 are untreated. These are the hardness samples: 5, 55, 6, and 66. Samples 5 and 55 are sandblasted in order to be quenched in water heat treatment, but samples 6 and 66 are not.

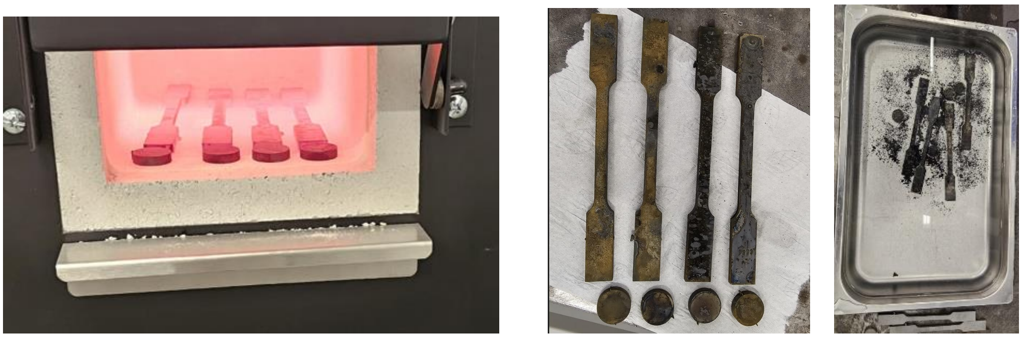


Figure 11: Quenching in water treatment process in furnace, and final results of the samples.

4.2.4. Untreated and Sandblasted Samples without heat treatment process

Untreated and sand blasted samples are mentioned in figure 13. Four untreated samples have been generated for the purpose to compare the hardness levels of all the treated samples in this study. These four samples consist of two that have only been sandblasted and two that have only been edge prepped. Correlating the outcomes of all treated samples with those samples is done using these samples. Those samples are based on table 3 which are 7, 77, 8, and 88 in order. In this research, samples 8 and 88 are untreated, whereas samples 7 and 77 have been subjected to sandblasting.

Figure 12: Untreated and sand blasted samples of tensile and hardness testing.

4.3. Hardness testing

There are different heat-treated samples used in this hardness testing. Samples are prepared based on testing standards. In hardness testing, the samples are polished with the help of a mirror polishing machine. Vickers hardness testing is performed on each sample. The figure 14 right side image is explaining annealing treated sample results, and the figure 14 left side image is explaining normalizing treated sample results. In the annealing hardness results in the middle square sections is the Dimond tool penetration part. To mark this shape, the machine is measuring the applied force on the test specimen and calculating the hardness value from the image. After the annealing process, the image described particular microstructure properties in well-defined grain patterns. Each grain shows a uniform and smooth surface, which shows that the annealing process successfully dissipated irregularities or stress. and also, the image, which shows a slightly dark shape, indicating higher hardness, and the other side, which appears to have lower hardness. All procedures are the same for normalizing, quenching in water, and other samples. (All results are mentioned in appendix).

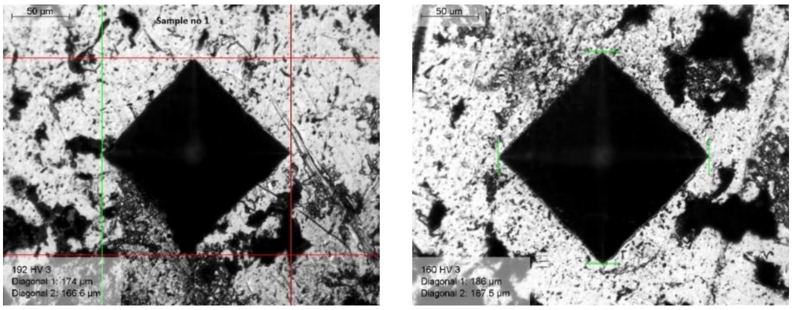


Figure 13: Annealing and Normalising Heat-treated samples hardness result

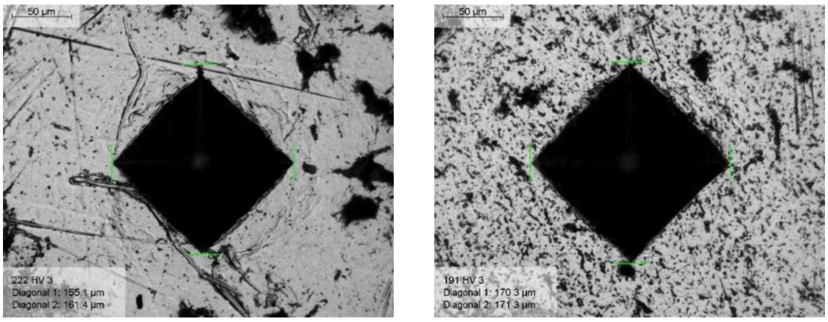


Figure 14: Quenching in water heat treated and sandblasted sample results

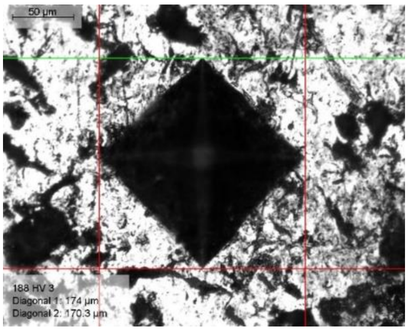


Figure 15: Untreated samples hardness result

Figure 17 explained all hardness results in one graph. Multiple samples were examined, and their applied force and hardness values measured as part of a study on different heat treatment procedures, such as annealing, normalising, quenching in water, sandblasting, and untreated conditions. Using three grammes of applied force on four samples, the hardness values for the annealing procedure varied from 192 to 200. With the same 3g force applied, the hardness ratings decreased during the normalising process from 152 to 160. Hardness values after quenching in water were much greater, ranging from 221 to 258 when 3g of force was applied. The hardness values of the sandblasted samples were 191 and 194, respectively, when 3g of force was applied. Last but not least, two samples with an applied force of 3g and hardness values of 176 and 188 were left untreated. The highest hardness values among the studied procedures were obtained by quenching the material in water. These results provide light on the effects of various heat treatment processes on material hardness. After annealing treated samples hardness values, the image displays a refined and uniform grain structure; the normalizing specimen image displays a slightly coarser grain structure; and quenching in water-treated samples shows chaotic assembly.(Original graph is attached in appendix)

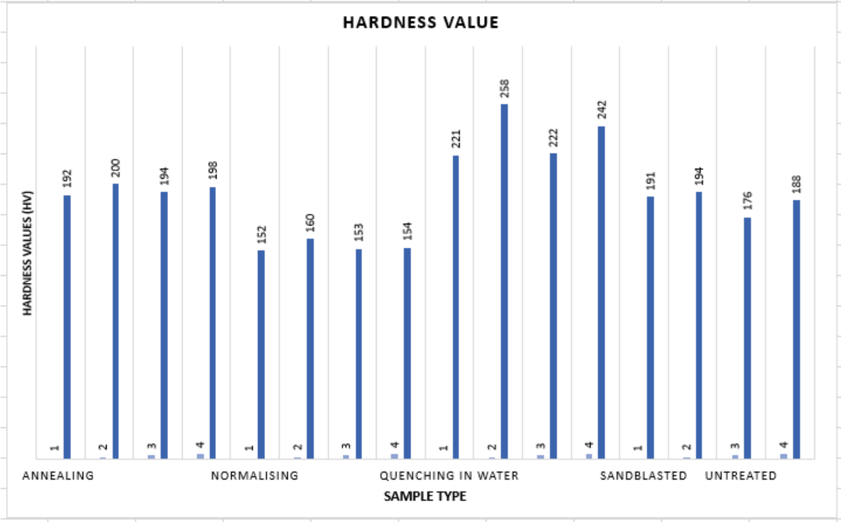


Figure 16: Comparison of all hardness results.

4.4. Microscopic Examination

Figures 18–20 provide a comprehensive insight into the microscopic examination of the samples, with over 100 results meticulously compiled from the test specimens. These results represent the mean outcomes of each treatment process. Figure 18 elucidates the examination results, distinguishing between the left-side annealing heat treatment and the right-side normalising heat treatment. In Figure 19, the left portion encompasses results from quenching in water, while the right portion features results from the sandblasted samples. Lastly, Figure 20 offers a detailed analysis of the microscopic examination results of the untreated samples.

When comparing the images of untreated samples with annealing-treated samples, it is noticeable that untreated samples display a coarse, irregular, and heterogeneous microstructure with variation in grain structure. In annealing-treated samples, the microstructure is finer and more uniform, indicating reduced defects and internal stress. This transformation is increasing the material's mechanical properties. When images of untreated samples are compared to images of normalizing-treated samples, it is clear that the untreated samples have a microstructure that is not uniform and course, with a variable grain structure. In normalizing treated samples, the image displays more refined, uniform, and improved homogeneity, which is improving the mechanical properties of the metal. but after normalizing, the values of hardness became higher compared to untreated samples.

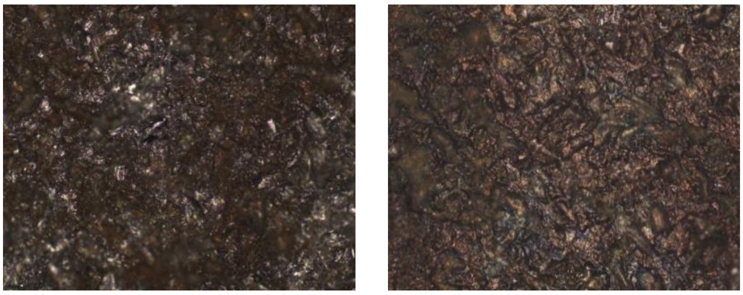


Figure 17: Annealing samples and Normalising Samples

When comparing the quenching of heat-treated samples to untreated samples, it is noticeable that untreated material usually has a well-organized, homogenous microstructure with a constant hardness before quenching. Quenching in treated samples displays severe fluctuations in hardness and the creation of martensitic structures, resulting in a chaotic state. This demonstrates how quenching has a substantial impact on the mechanical and microstructure of the material.

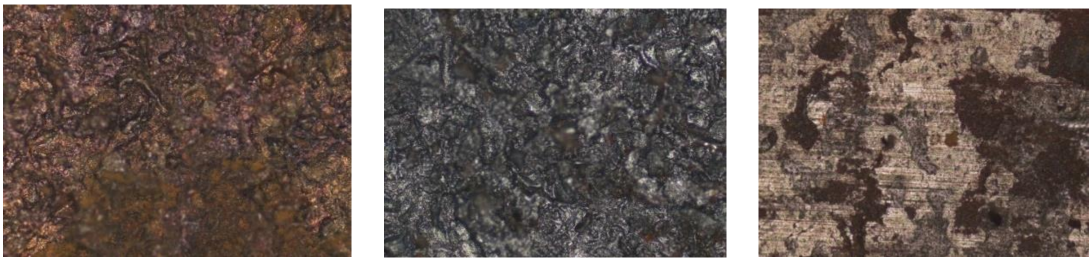


Figure 18: Quenching in water sample, sandblasting sample, Untreated sample

The heat treatment process applied to the test specimen involves a sequence of steps, including annealing, normalising, and quenching in water. Upon microscopic examination, it becomes evident that each heat treatment process imparts distinct colours to the specimen. However, it is essential to clarify that these colour variations do not directly correlate with the treatment process itself. Instead, some of the samples exhibit subtle signs of corrosion, which might not be readily detectable within the scope of this project. As a result, the only samples identified by colour are the untreated ones and those that have undergone sandblasting, making them distinguishable from the rest.

4.5. SEM Machine Results (Scanning Electron Microscope)

The SEM examination is an integral part of the microscopic analysis in this study. In a conventional microscopic examination (Figure 21 to 26). discerning the grain structure within the samples proves to be a challenging task. The figure explains the SEM examination. Figure 21 explains the test specimen in the SEM machine. Figure 22 explains the 1mm zoom in two different shades. Figure 23 is explaining the 100-micron zoom, where the final grain structure is collected at 1 micrometre in Figure 26.However, through the application of SEM examination, we have successfully identified the grain structures of all the test specimens in this project. Upon close inspection, it becomes apparent that the annealing-treated samples exhibit grain structures that are closely packed (Figure 14 and 18), indicative of a coarse perlite structure. In the normalising samples, minor closely spaced grain structures are observed, signifying a fine perlite grain structure (Figure 14 and 18). For the samples subjected to quenching in water, the grain structure displays few discernible gaps between the grains, indicating a martensite structure (Figure 15 and 19). The identification of these various grain structures provides a crucial insight, demonstrating the success of the heat treatment processes conducted within this project. This comprehensive analysis of the grain structures underscores the effectiveness of the heat treatment procedures employed.

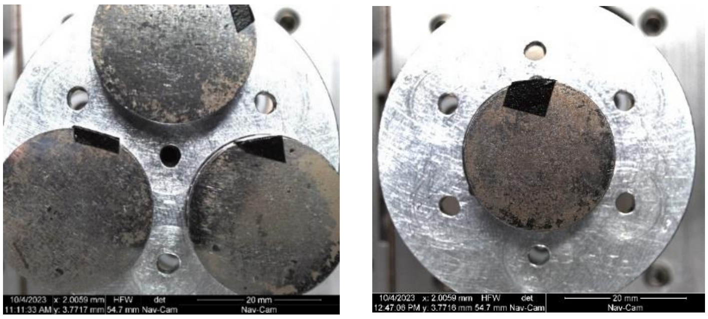


Figure 19: Samples in SEM machine

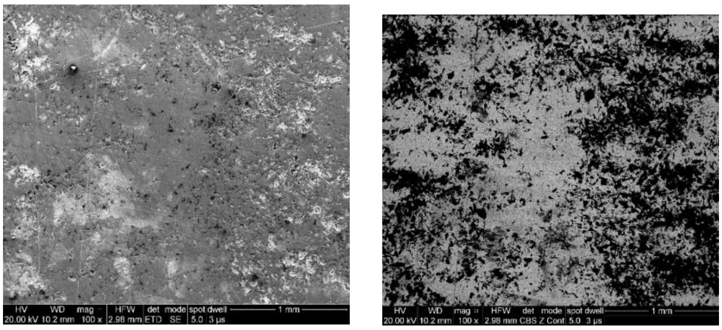


Figure 20: SEM results at 1mm.

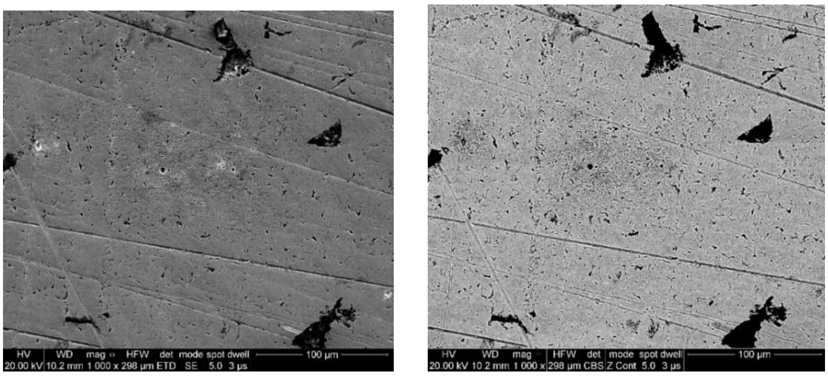


Figure 21: SEM results at 100 micro meters

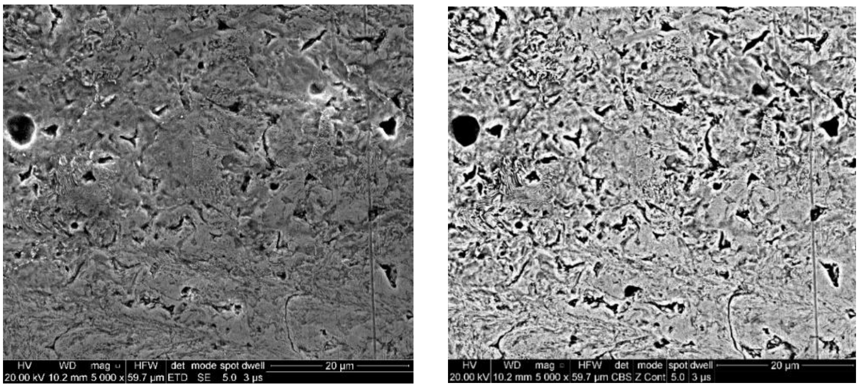


Figure 22: SEM Results at 20 micro meters.

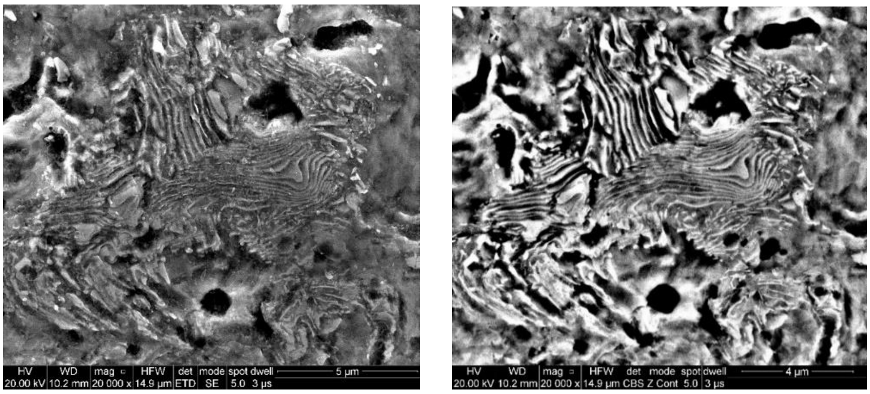


Figure 23: SEM Results at 5 and 4 micro meters.

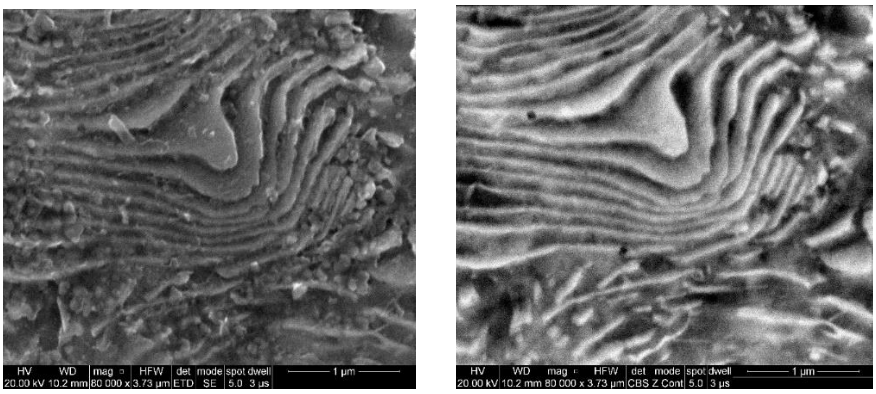


Figure 24: Final SEM results at 1 micrometre

4.5.1. EDX results

In this project, surface contamination detection and microanalysis are carried out using energy-dispersive X-ray spectroscopy (EDX), a highly effective analytical instrument. With the use of EDX, we were able accurately determine the samples' elemental composition, which was helpful in identifying any surface contamination and micro-level structures. This skill was crucial to guaranteeing the accuracy of the project's findings and to obtaining a thorough grasp of the materials being studied.

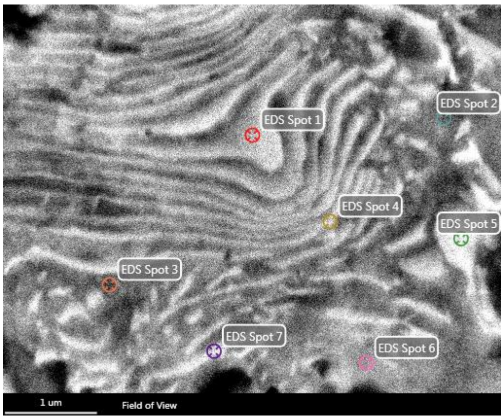
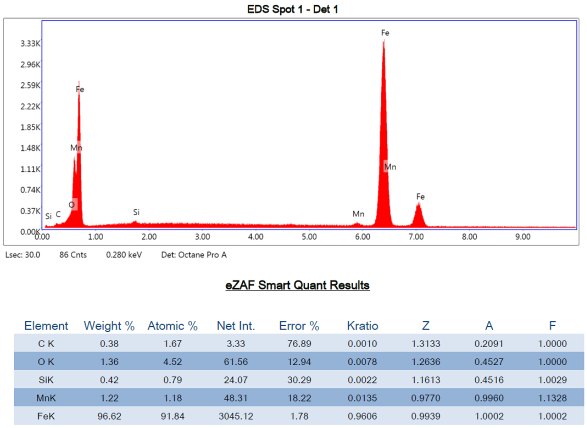


Figure 25: DEX results with targeted points.

In this project, our focus cantered on the intricate examination of material properties through the application of Energy Dispersive X-ray (EDX) analyses, a technique effectively executed on the Scanning Electron Microscopy (SEM) machine. The overarching objective of this study was to elucidate the transformative impact of diverse heat treatment processes on the material characteristics of a specific test specimen. The significance of this endeavour lay in unravelling the intricate alterations that occur within the material following various heat treatments – whether certain components or particulate matter from the specimen dissolved into the metal, or if any novel chemical elements were introduced as a result of chemical reactions. To foster a comprehensive understanding, the manufacturing company generously shared comprehensive information regarding the components constituting the test specimen's material. During the EDX analysis, we meticulously selected various spots across the specimen, each representing a distinct method of material data collection. These selected spots allowed us to collect data on elemental composition and concentration, vital for the subsequent comparison to the initial composition specified by the manufacturing company. The outcomes of our analyses and the subsequent juxtaposition with the company's material specifications yielded intriguing findings. Notably, we observed only minimal variations in the levels of magnesium and oxygen within the material composition. These insightful findings, presented in the appendix along with the detailed information provided by the manufacturing company, underscore the critical role of EDX analyses in the realm of material science, particularly in the assessment of the consequences of thermal treatments on material properties. This research thus not only contributes to our understanding of the dynamic interplay between heat treatment and material composition but also carries profound implications for enhancing the efficiency of industrial and manufacturing processes.



eZAF Smart Quant Results

Element	Weight %	Atomic %	Net Int.	Error %	Kratio	Z	A	F
C K	0.38	1.67	3.33	76.89	0.0010	1.3133	0.2091	1.0000
O K	1.36	4.52	61.56	12.94	0.0078	1.2636	0.4527	1.0000
SiK	0.42	0.79	24.07	30.29	0.0022	1.1613	0.4516	1.0029
MnK	1.22	1.18	48.31	18.22	0.0135	0.9770	0.9960	1.1328
FeK	96.62	91.84	3045.12	1.78	0.9606	0.9939	1.0002	1.0002

Figure 26: EDX results at targeted at spot 1

In the details analysis of the EDX image (Figures 28–32), it can be noticed that the values of Fe content range between 2.70k and 3.62k in some portions, while Fe content also shows values around 0.45k in the image. However, manganese content values between 1.40K and 1.22K in some portions. but the chemical properties from the manufacturing values are mentioned in the appendix. All results are mentioned in the appendix.

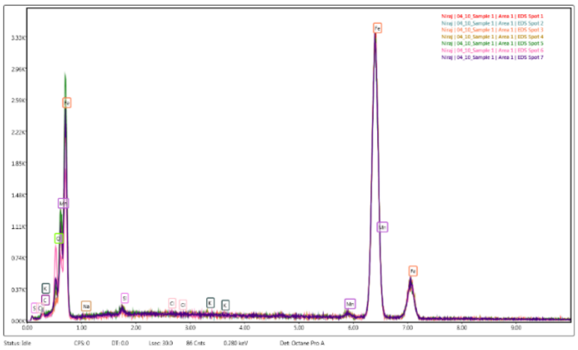


Figure 27: Annealing EDX results with targeted spots.

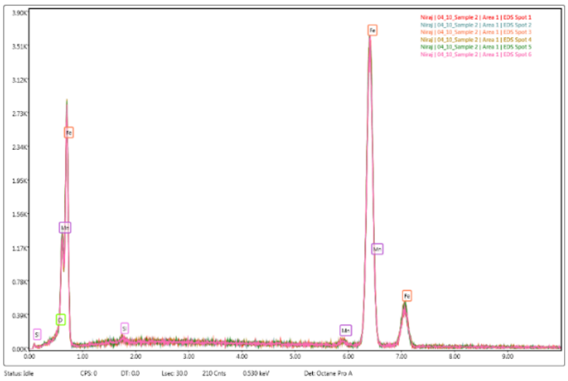


Figure 28: Normalising EDX results with targeted spots.

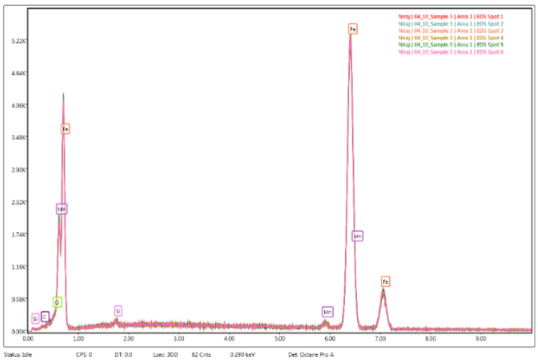


Figure 29: Quenching in water EDX results with targeted spots.

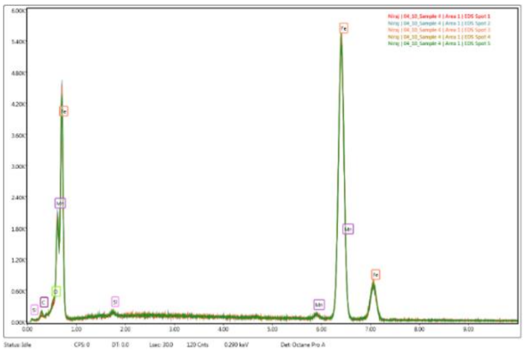
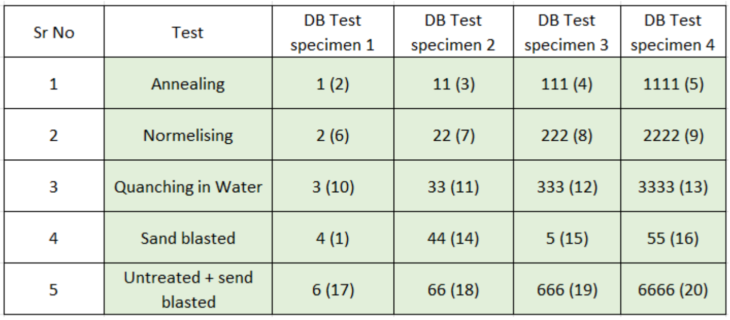


Figure 30: Untreated samples EDX results with targeted samples.

4.6. Tensile testing

Tensile test5ing samples Annealing, normalising, sandblasted, and untreated sample results are mentioned in the table 4 and Figure 33. Tensile testing is performed in the Instron machine at Flinders University. To collect the mechanical properties of the metal, tensile testing is performed in this project. A total of 19 test specimens were tested in this procedure, of which 4 were quenched in the water heat treatment process. The prepared test specimen has a high strength after the treatment process, and the machine has only a 50KN capacity to break it. This research could not collect the quenching in water-treated test specimens as results from the machine. There are no results collected from the one (sample no. 20) spare sample. Each treatment process has four dog bone test specimens, and tensile testing results are collected from each treatment process.

Figure 31: After tensile testing all dogbane test specimen.



Sr No	Test	DB Test specimen 1	DB Test specimen 2	DB Test specimen 3	DB Test specimen 4
1	Annealing	1 (2)	11 (3)	111 (4)	1111 (5)
2	Normelising	2 (6)	22 (7)	222 (8)	2222 (9)
3	Quanching in Water	3 (10)	33 (11)	333 (12)	3333 (13)
4	Sand blasted	4 (1)	44 (14)	5 (15)	55 (16)
5	Untreated + send blasted	6 (17)	66 (18)	666 (19)	6666 (20)

Table 4 : Tensile testing samples new marking

4.6.1. Stress Strain Diagram of Tensile testing samples

Tensile testing is conducted utilising the Instron machine, a precise apparatus capable of applying forces to a test specimen until it ultimately reaches the point of rupture. During this rigorous evaluation, an extensometer plays a pivotal role by meticulously monitoring and detecting any changes occurring within the material. The extensometer seamlessly integrates with specialised software, which efficiently collects and organises the resulting data into both graphical representations and Excel files. However, as with any analytical process, occasional challenges arise, and there may be instances when the data points do not align precisely due to calibration errors. In the context of this project, a meticulous comparison is undertaken, meticulously scrutinising the graphical representations, and ensuring seamless alignment of all details. This rigorous process is essential to verifying the accuracy of all tensile testing results in accordance with the provided information. Ultimately, the meticulous scrutiny and alignment of the data assure the validity and precision of the obtained tensile testing results. (All graphs and images are mentioned in appendix).

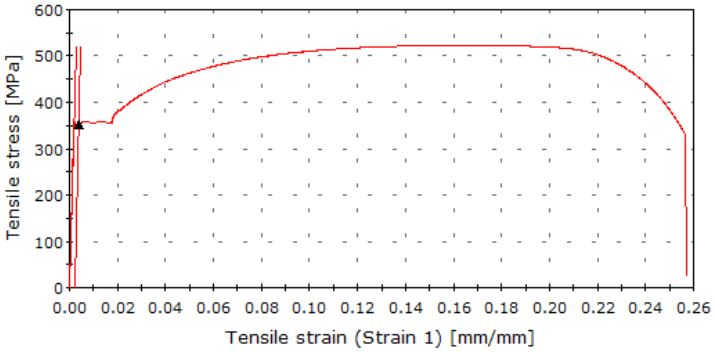


Figure 32: Sample no 2-stress vs strain diagram (Annealing treated samples data).

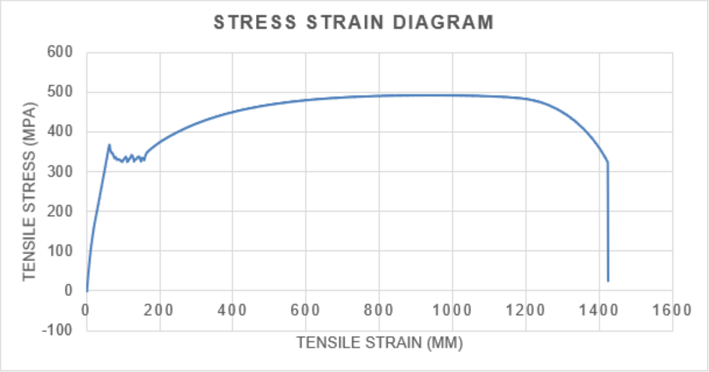


Figure 33: Data sheet (information) generated stress vs strain diagram.

4.6.2. Young’s Modulus from the tensile testing

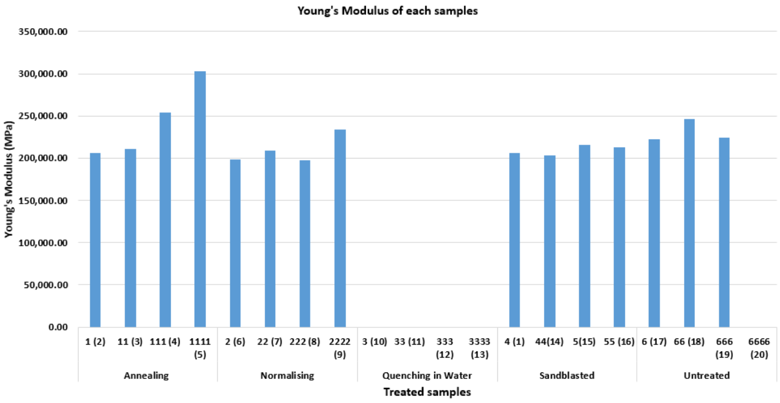


Figure 34: Young's modulus of all samples

The table displays information on the mechanical characteristics of samples that performed various heat treatment procedures. Young's modulus readings through a range of 197,926.45 MPa to 303,224.01 MPa, while sample hardness ranged from 335.35 MPa to 517.95 MPa during the 'Annealing' processes. The maximum loads that were applied ranged from 25,969 N to 28,236.24 N, or from 25.97 KN to 28.24 KN. Tensile stress varied from 473.81 MPa to 533.59 MPa during the "Normalising" process, and Young's modulus values varied from 198,050.01 MPa to 234,232.35 MPa. The maximum loads were 25,585.83 N to 28,813.75 N, or 25.59 kN to 28.81 kN. Sadly, the hardness of the quenching in the water heat treatment sample is higher than in the other samples, even though the institution has an instorn machine with a 50KN capacity. This test specimen cannot be easily broken by the machine. To break this sample, higher load capacity is required. For this reason, the quenching in the water heat treatment sample is not reported. The 'Sandblasted' samples have Young's modulus values ranging from 203,627.26 MPa to 215,978.70 MPa, and tensile stress values between 460.05 MPa and 524.99 MPa of tensile stress. Between 24,842.71 N and 28,349.41 N, or 24.84 KN and 28.35 KN, were the maximum loads that were applied. Last but not least, in the 'Untreated' condition, maximum loads varied from 24,956.69 N to 28,790.26 N (equivalent to 24.96 KN to 28.79 KN), tensile stress ranged from 462.16 MPa to 533.15 MPa, and Young's modulus values ranged from 222,285.33 MPa to 246,369.02 MPa. The data demonstrates how various heat treatment procedures might result in differences in mechanical properties.

4.7. MATLAB Software results

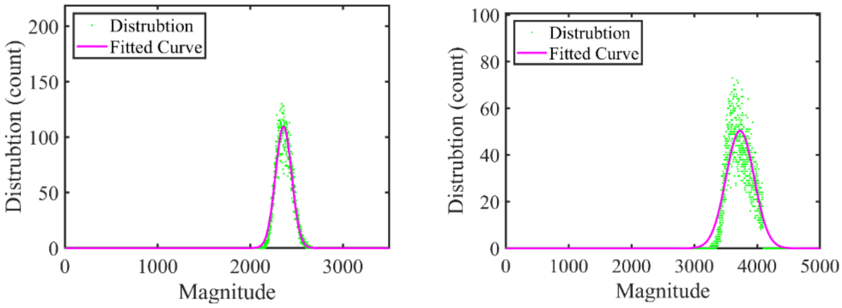


Figure 35: Before and after annealing heat treatment process sample no 1.

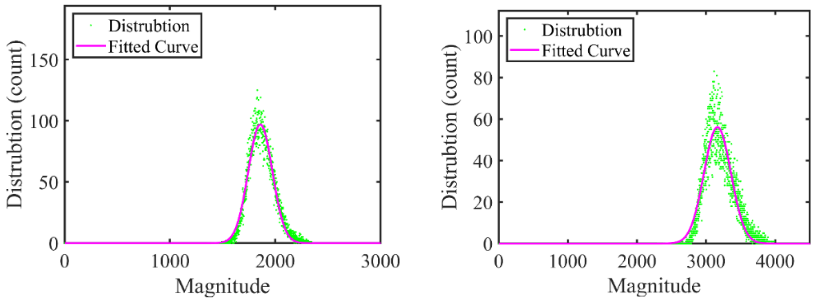


Figure 36: Before and after Normalising heat treatment process sample no 1.

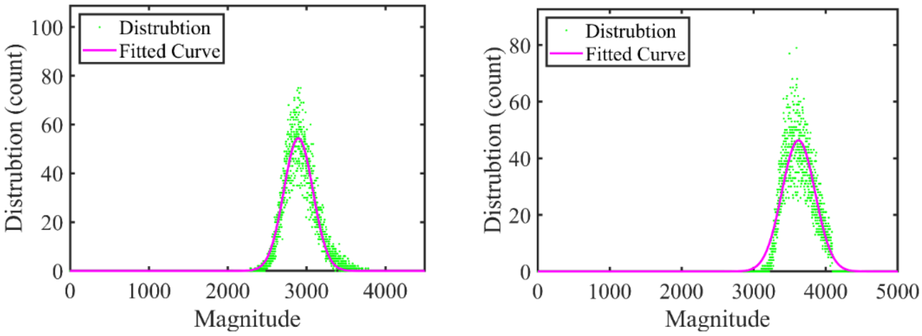


Figure 37: Before and after Quenching in water heat treatment process sample no 1.

Data from three different heat treatment processes—annealing, normalising, and quenching in water—are displayed in the graph. Four different samples were treated using these techniques, and the temperature readings before and after each treatment are shown in the Figure 38. The initial magnitudes of the samples varied between 453 and 502 for the annealing procedure. With after treatment magnitudes ranging from 488 to 566, these values significantly rose following therapy. This suggests a significant increase in magnitude as a result of annealing. The range of sample beginning magnitudes in the normalisation example was 407 to 521. These magnitudes likewise increased following treatment, ranging from 517 to 680, showing that the effect of annealing was comparable in terms of magnitude enhancing. On the other hand, more notable alterations resulted from the quenching in water process. These samples' initial magnitudes ranged from 476 to 536. Following treatment, they saw a significant increase, with values between 710 and 752. This indicates that, in comparison to the other methods, the quenching in water process had the most noticeable effect on magnitude.

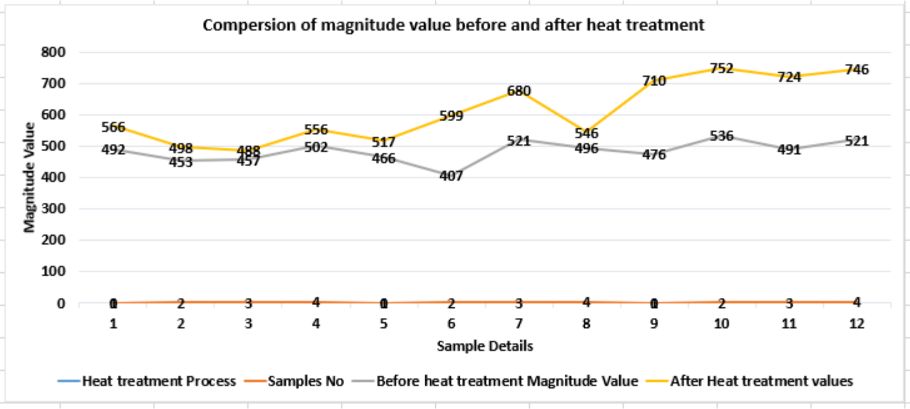


Figure 38: Comparison of magnitude values from the MATLAB before and after heat treatment process

4.7.1. Pixels values from the MATLAB

X-ray images are analysed using MATLAB code within the MATLAB software. In these images, regions with a higher density exhibit brighter areas with correspondingly high pixel values, while regions with a lower density appear darker with lower pixel values. Utilizing this principle, the MATLAB software is employed to extract data from the X-ray images. The X-ray data is focused on specific areas within the images, allowing MATLAB to generate magnitude and density values as well as a visual representation of the image. These values are gathered both prior to and after subjecting the material to heat treatment. Upon making modifications to the code, pixel values are directly extracted in MATLAB.

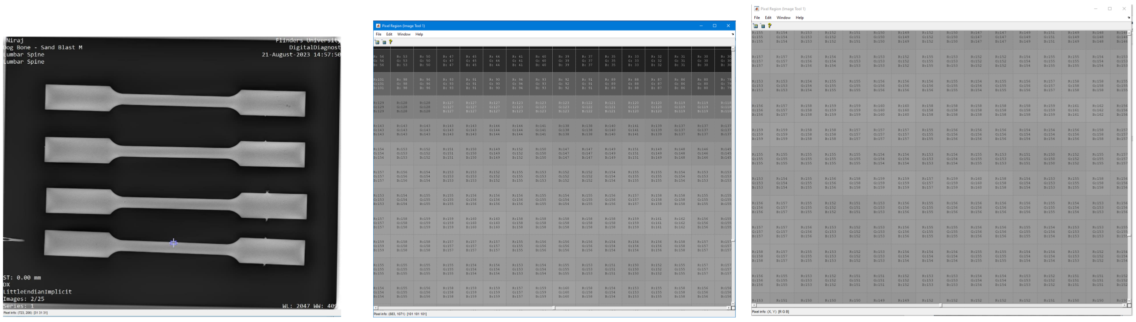


Figure 39: Pixels values from test specimen using MATLAB.

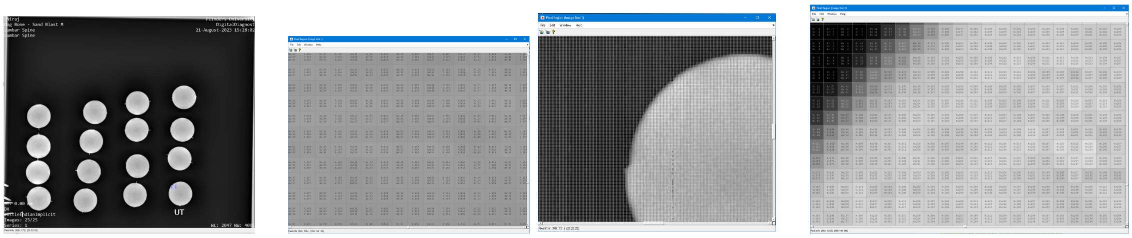


Figure 40: Pixels values of the hardness samples.

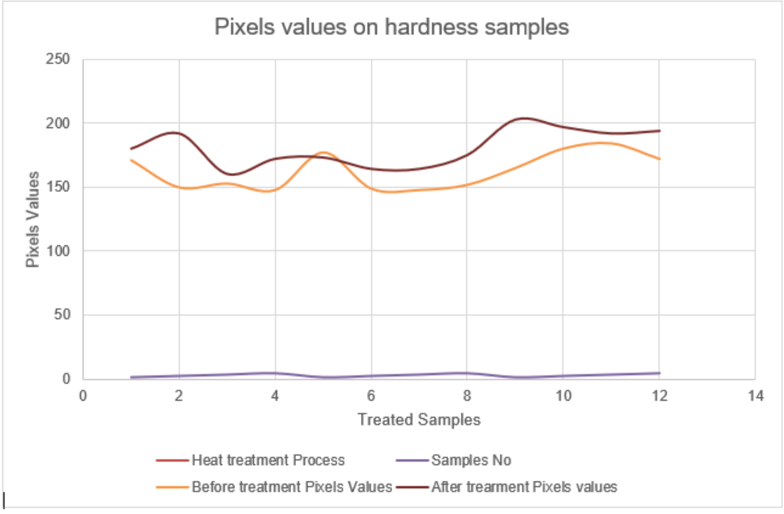


Figure 41: Pixel’s values comparison

Figure 41 explaining the pixels values from the hardness test specimen. (More details are mentioned in the Appendix). There is a problem in the MATLAB codes in the tensile testing pixels values are not collected in this research. However, when comparing the results obtained from MATLAB before and after modification, it becomes apparent that the values are not closely aligned. This discrepancy may be attributed to the inherent limitations in discerning the material properties of the metal within the X-ray images

5. Conclusion

The experimental and theoretical data in this project were carefully looked at using a variety of methods, such as heat treatment, hardness testing, tensile testing, MATLAB analysis, DICOM images, and SEM microscopy. The results clearly show that the material has unique properties. The application of annealing, normalising, and quenching within the heat treatment process notably alters the material properties of the steel. Hardness testing serves as a key indicator of these transformations, clearly demonstrating a significant alteration in the material's properties post-heat treatment. This alteration is most pronounced in the hardness results, validating the efficacy of the heat treatment process. In investigating the grain structure, SEM (scanning electron microscopy) emerges as a superior examination technique compared to conventional optical microscopy. SEM enables a detailed assessment of the grain structure, revealing the presence of distinct phases such as austenite, pearlite, or fine-grained structures. The utilisation of MATLAB software facilitates the extraction of pixel values from X-ray images.

However, it is imperative that the images be provided in JPG format for accurate analysis. Upon a comprehensive review of all the results, it is important to note that, despite analysing density and magnitude values within the images, it may be challenging to definitively ascertain the material properties of the metal solely based on this information. Further research and analysis may be required to establish a more conclusive understanding of the material's characteristics.

5.1. Future Works

The material characteristics of steel under various heat treatment techniques were investigated in this extensive study using a multidisciplinary approach. It was discovered that the material has several properties that are significantly impacted by annealing, normalising, and quenching by the use of techniques including heat treatment, hardness testing, tensile testing, MATLAB analysis, DICOM image evaluation, and SEM microscopy. In hardness testing, the change was clearly noticeable, offering strong confirmation of the heat treatment procedure's effectiveness. SEM is superior to conventional microscopy for deciphering complex grain structures. It demonstrated the presence of fine-grained structures, austenite, and pearlite. Although MATLAB made it easier to extract pixel values from X-ray images, more investigation and analysis was required due to the difficulties in determining material properties based only on image density and magnitude. In order to optimise material properties and their practical applications while addressing data standardisation and interdisciplinary collaboration, future work should investigate advanced material characterization, microstructure analysis, correlation studies, machine learning applications, and real-world testing. This multidisciplinary research strategy should provide a more thorough understanding of the material behaviour of steel.

BIBLIOGRAPHY

Barth, H. Z. (2011). Characterization of the effects of x-ray irradiation on the hierarchical structure and mechanical properties of human cortical bone. *Biomaterials, 32(34)*, 8892-8904.

Bayu, A. h. (2018). Measurement of metal thickness using X-ray computed radiography. .

Cortial, F. C.-L. (1995.). Influence of heat treatments on microstructure, mechanical properties, and corrosion resistance of weld alloy 625. . *Metallurgical and Materials Transactions A, 26,* , 1273-1286.

Dhoska, K. (2019). Tensile Testing Analysis of the HRB400 Steel Reinforcement Bar. *International Journal of Innovative Technology and Interdisciplinary Sciences, 2(3),* , 253-258.

Du, Z. X. (2014.). Effect of heat treatment on microstructure and mechanical properties of a new β high strength titanium alloy. . *Materials & Design, 55*, 183-190.

Dumont, V. B. (2020). On the influence of mechanical loadings on the porosities of structural epoxy adhesives joints by means of in-situ X-ray microtomography. . *International Journal of Adhesion and Adhesives, 99.*, 102598.

Guo, W. Q. (July, 2018). WDXI: The dataset of X-ray image for weld defects. In 2018 14th International Conference on Natural Computation, Fuzzy Systems and Knowledge Discovery (ICNC-FSKD). *IEEE*, 1015-1055.

I.C. Sinka, S. B. (2004). Measurement of Density variations in tablets using X-ray computed tomography. *International journal of pharmaceurics 271.*, 215-224.

Instructables. (2017). Normalizing carbon steel.

John. (2023, 10 10). *Annealing vs Normalizing vs Tempering vs Quenching - Ultimate Comparison Guide,* . Retrieved from www.Metalworkmasters.com.

Kaczmarczyk, G. K. (2022). Application of X-ray Computed Tomography to Verify Bond Failures Mechanism of Fiber-Reinforced Fine-Grain Concrete. *materials, 15(6)*, 2193.

Kafka, O. Y. (2022). X-ray computed tomography analysis of pore deformation in IN718 made with directed energy deposition via in-situ tensile testing. *International journal of Solids and Structures, 256.*, 111943.

Kim, F. M. (2020). Investigation of the effect of artificial internal defects on the tensile behavior of laser powder bed fusion 17–4 stainless steel samples: simultaneous tensile testing and X-ray computed tomography. . *Experimental mechanics, 60,*, 987-1004.

Kong, W. W. (2020). Research progress on cement- based materials by X-ray computed tomography. *International Journal of Pavement Research and technology, 12*, 366-375.

Lashkia, V. (2001). Defect detection in X-ray images using fuzzy reasoning. *Image and vision computing, 19(5)*, 261-269.

Li, Z. L. (2020). In-situ 3D characterization of tensile damage mechanisms in A319 aluminium alloy using X-ray tomography and digital volume correlation. . *Material Science and Engineering: A. 794*, 139920.

Liu, P. H. (2020.). Effect of heat treatment on microstructure, hardness and corrosion resistance of 7075 Al alloys fabricated by SLM. . *Journal of Manufacturing Processes, 60,* , 578-585.

Lopresti, M. A. (2020). Light weight, easy formable and non-toxic polymer-based composites for hard x-ray shielding: a theoretical and experimental study. . *International journal of molecular science, 21(3)*, 833.

Lu, T. C. (2020). Comparison of low-velocity impact damage in thermoplastic and thermoset composites by non-destructive three-dimensional X- ray microscope. . *Polumer Testing, 91.*, 106730.

Markötter, H. M. (2023). A review of the X-ray imageing at the BAMLIne (BESSY 2). *Advanced Engineering Materials.* .

Nikseresht, Z. K. (2010.). Effect of heat treatment on microstructure and corrosion behavior of Al6061 alloy weldment. . *Materials & Design (1980-2015), 31(5),* , 2643-2648.

Peng, J. T. (2011). Effect of heat treatment on microstructure and tensile properties of A356 alloys. . *Transactions of Nonferrous Metals Society of China, 21(9),* , 1950-1956.

Sahin, M. A. (2007.). Characterization of mechanical properties in AISI 1040 parts welded by friction welding. . *Materials characterization, 58(10),* , 1033-1038.

Shakil, M. A. (2014.). Microstructure and hardness studies of electron beam welded Inconel 625 and stainless steel 304L. *Vacuum, 110,*, 121-126.

Shane. (2023, 10 9). *Heat treatment processes,*. Retrieved from www.Machinemfg.com.: www.Machinemfg.com.

Spahn, M. (2013). X ray detectors in medical imaging. *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment,* , 57-63.

tec-science. (2023, 10 10). *Quenching and tempering*. Retrieved from tec-science.: www.tec-science.com

Wang, L. (2022). Microstructure and anisotropic tensile performance of 316L stainless steel manufactured by selective laser melting. Frattura ed Integrità Strutturale, 16(60), . *Frattura ed Integrità Strutturale, 16(60)*, 380-391.

Wang, Y. T. (2022). In-situ 3D observation of hydrogen-assisted particle damage behavior in 7075 Al alloy by synchrotron X-ray tomography. . *Acta Materialia, 227,*, 117658.

Wilson-Heid, A. N. (2019). Characterization of the effects of internal pores on tensile properties of additively manufactured austenitic stainless steel 316L. . *Experimental Mechanics, 59,* , 793-804.

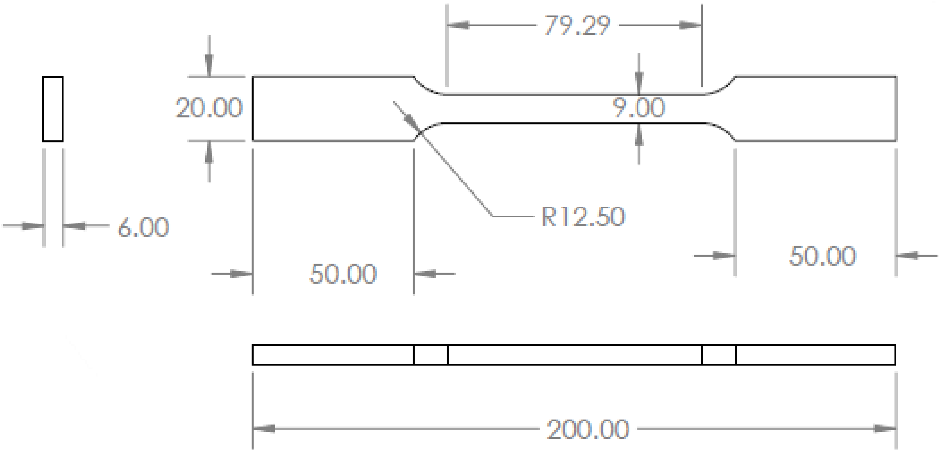
Xu, J. H. (2020). Experimental study on the bearing mechanisms of rock-socketed piles in soft rock based on micro X-ray CT analysis. . *Rock Mechanics and Rock Engineering, 53(8),*, 3395-3416.

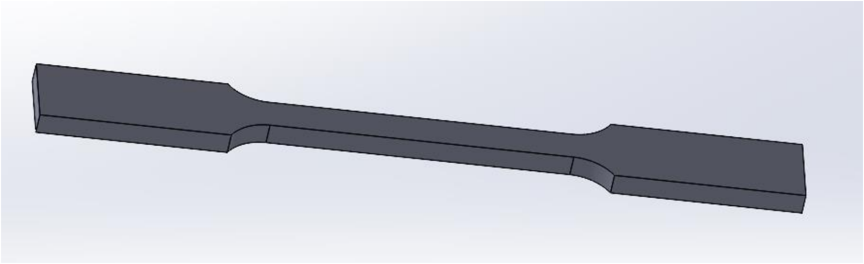
Zhang, H. P. (2022). Mesoscale Study on Splitting Tensile Damage Characteristics of Concrete Based on X-ray Computed Tomography and Digital Image Correlation Technology. . *Materials, 15(13),*, 4416.

Zhang, S. R. (2019). An experimental study of tensile property variability in selective laser melting. . *Journal of Manufacturing Processes, 43*, 26-35.

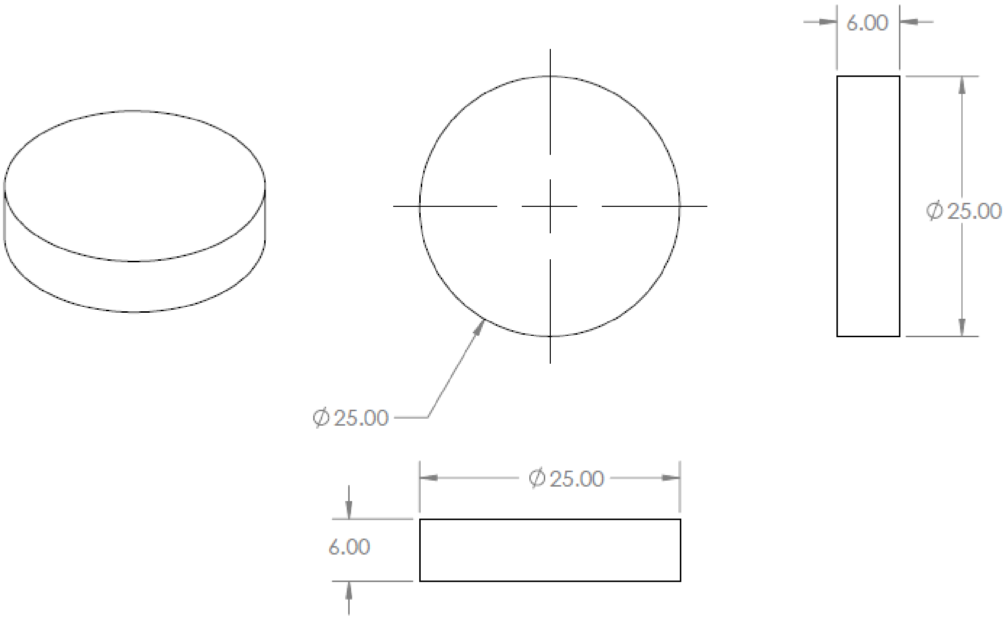
APPENDICES

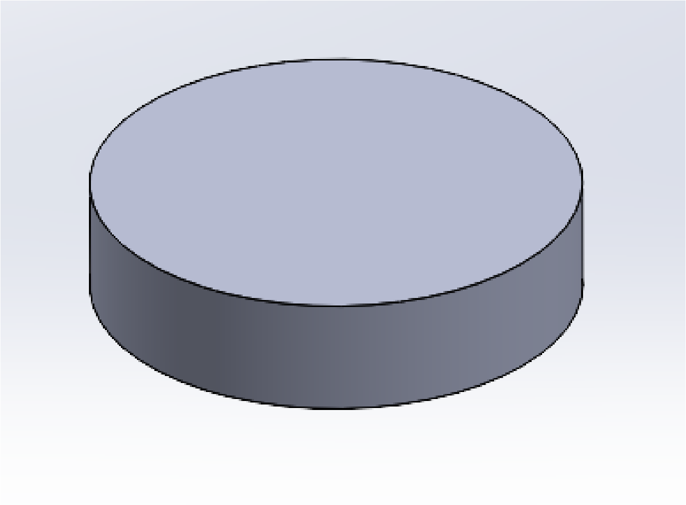
- Design of the tensile test specimen (Dog bone test specimen).





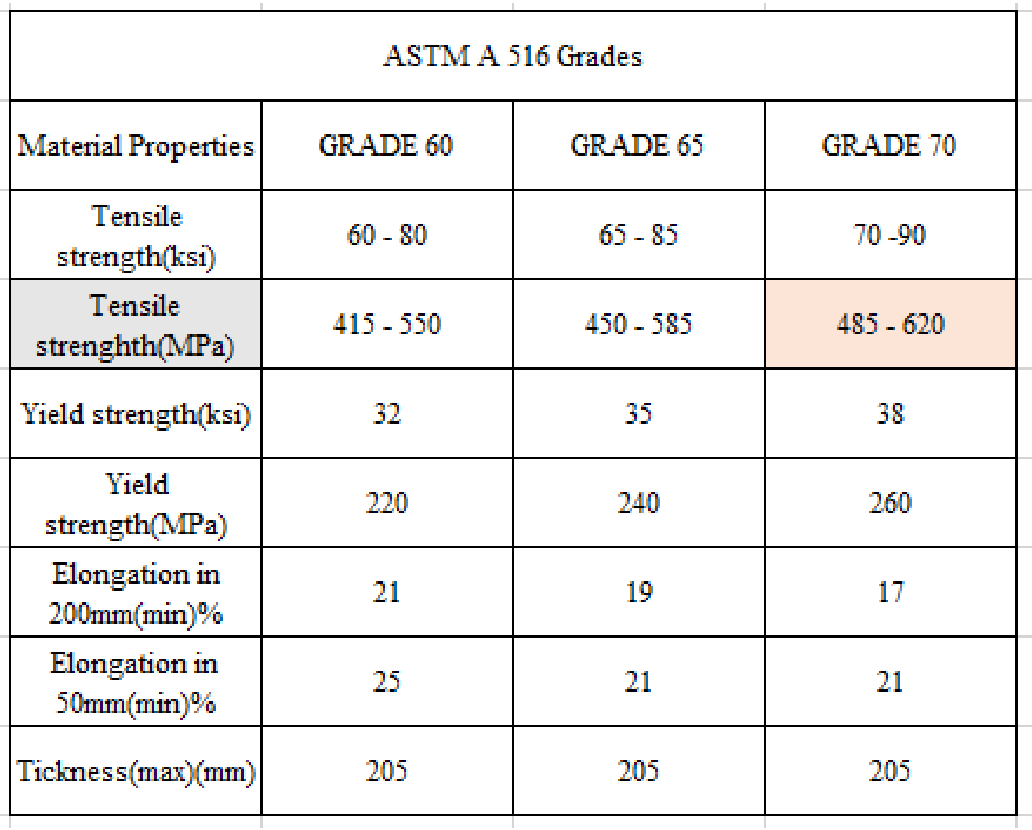
- Hardness test specimen design and dimensions.





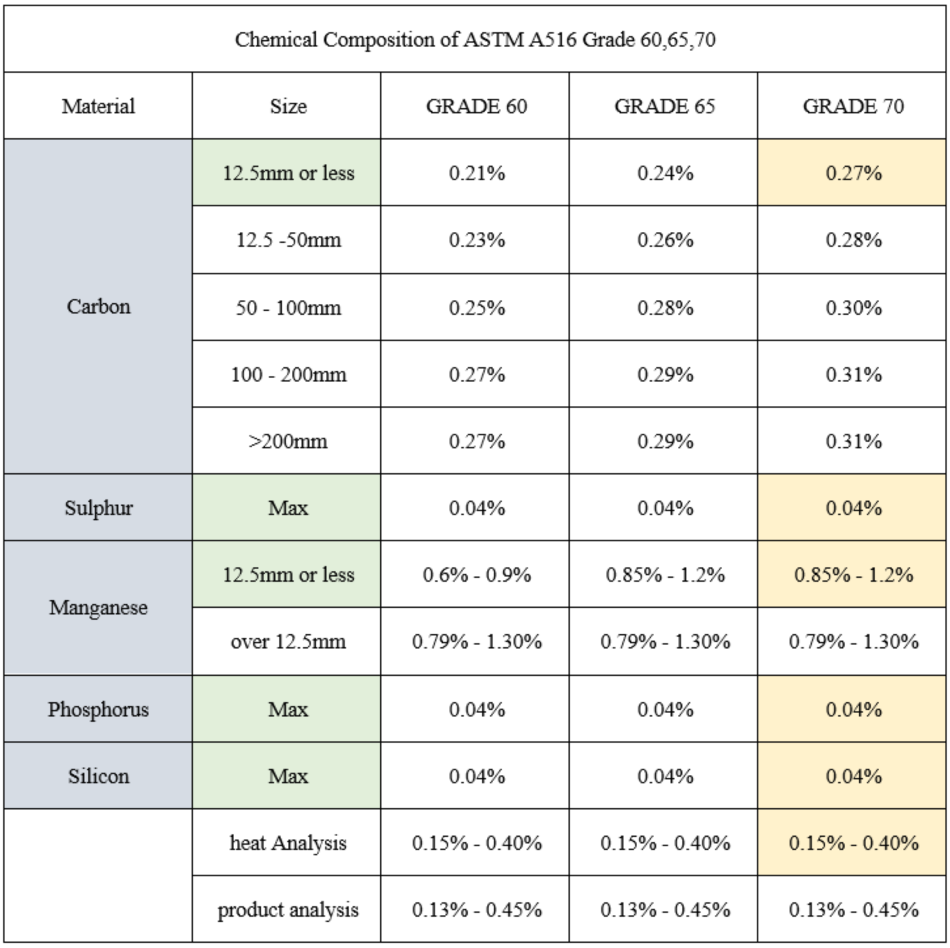
.

- ASTM A516 grade table



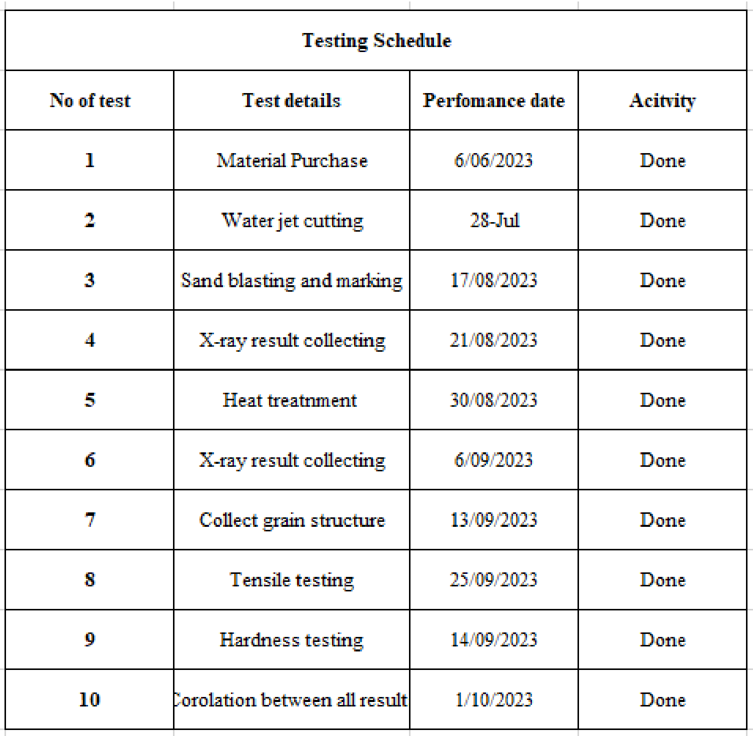
ASTM A 516 Grades			
Material Properties	GRADE 60	GRADE 65	GRADE 70
Tensile strength(ksi)	60 - 80	65 - 85	70 -90
Tensile strenghth(MPa)	415 - 550	450 - 585	485 - 620
Yield strength(ksi)	32	35	38
Yield strength(MPa)	220	240	260
Elongation in 200mm(min)%	21	19	17
Elongation in 50mm(min)%	25	21	21
Tickness(max)(mm)	205	205	205

- Details of steel ASTM A 516 grade 70



Chemical Composition of ASTM A516 Grade 60,65,70				
Material	Size	GRADE 60	GRADE 65	GRADE 70
Carbon	12.5mm or less	0.21%	0.24%	0.27%
	12.5 -50mm	0.23%	0.26%	0.28%
	50 - 100mm	0.25%	0.28%	0.30%
	100 - 200mm	0.27%	0.29%	0.31%
	>200mm	0.27%	0.29%	0.31%
Sulphur	Max	0.04%	0.04%	0.04%
Manganese	12.5mm or less	0.6% - 0.9%	0.85% - 1.2%	0.85% - 1.2%
	over 12.5mm	0.79% - 1.30%	0.79% - 1.30%	0.79% - 1.30%
Phosphorus	Max	0.04%	0.04%	0.04%
Silicon	Max	0.04%	0.04%	0.04%
	heat Analysis	0.15% - 0.40%	0.15% - 0.40%	0.15% - 0.40%
	product analysis	0.13% - 0.45%	0.13% - 0.45%	0.13% - 0.45%

- Performed testing.



Testing Schedule			
No of test	**Test details**	**Perfomance date**	**Acitvity**
1	Material Purchase	6/06/2023	Done
2	Water jet cutting	28-Jul	Done
3	Sand blasting and marking	17/08/2023	Done
4	X-ray result collecting	21/08/2023	Done
5	Heat treatment	30/08/2023	Done
6	X-ray result collecting	6/09/2023	Done
7	Collect grain structure	13/09/2023	Done
8	Tensile testing	25/09/2023	Done
9	Hardness testing	14/09/2023	Done
10	Corolation between all result	1/10/2023	Done

- Sample identification table

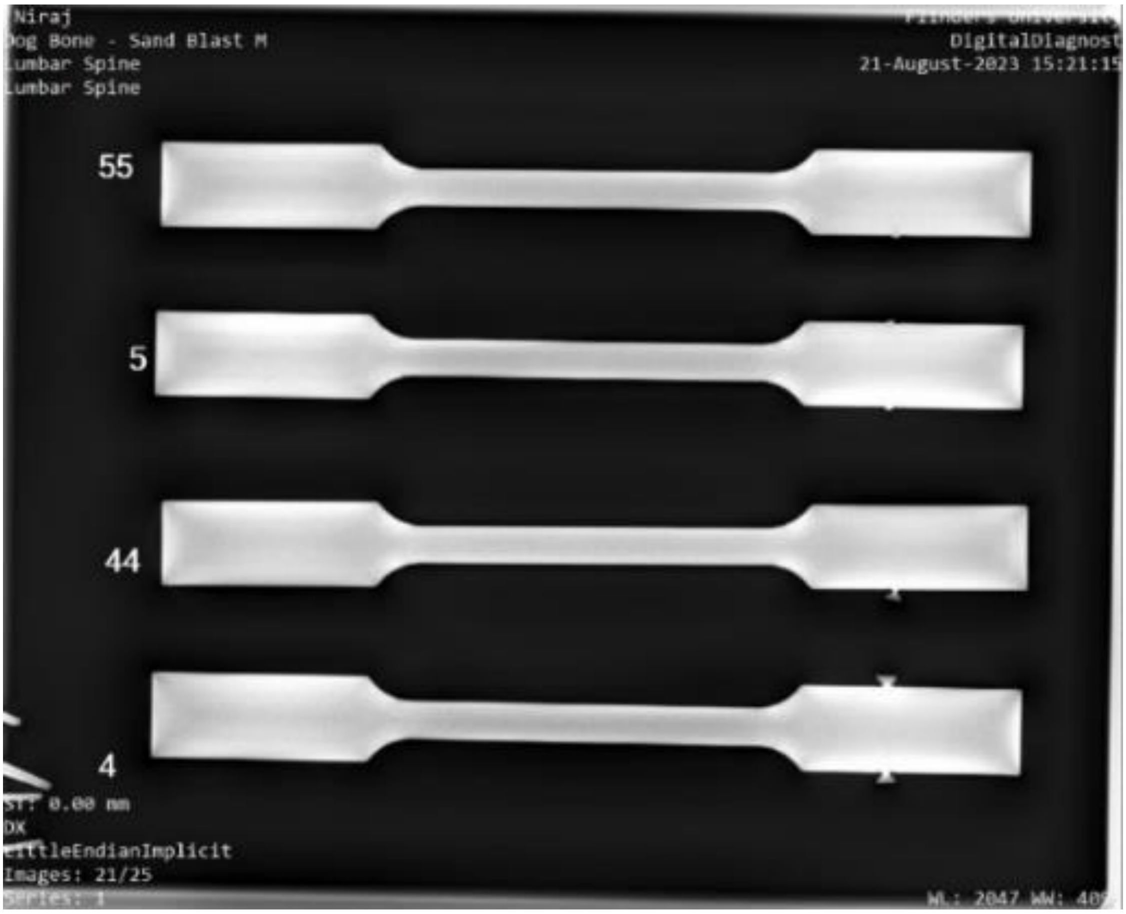
Heat treatment process for Steel ASTM A516 grade 70									
Punching or Marking for Test specimen									
Sr No	Test	DB Test specimen 1	DB Test specimen 2	DB Test specimen 3	DB Test specimen 4	R Test specimen 5	R Test specimen 6	R Test specimen 5	R Test specimen 6
1	Annealing	1	11	111	1111	1	11	2	22
2	Normelising	2	22	222	2222	3	33	4	44
3	Quanching in Water	3	33	333	3333	5	55	6	66
4	Sand blasted	4	44	5	55	7	77		
5	Untreated	6	66	666	6666	8	88		

- Sample preparation at CNC Cutting services.

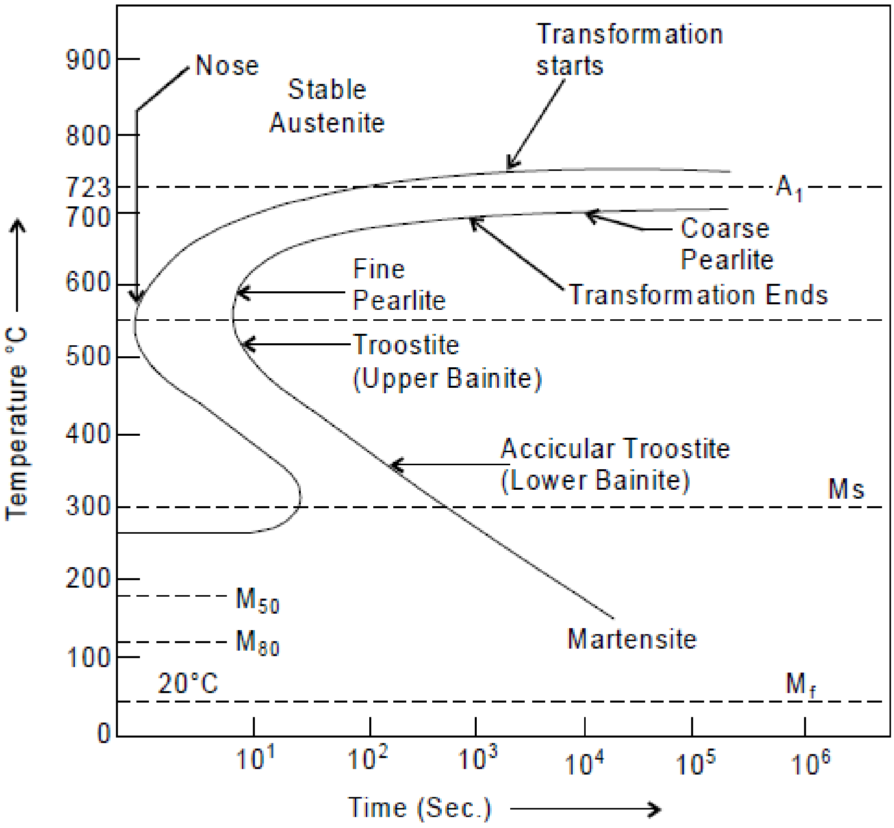
- Sample prepared from the CNC cutting Services.

- X ray results are collected in the machine.

- X ray results are marked in software.



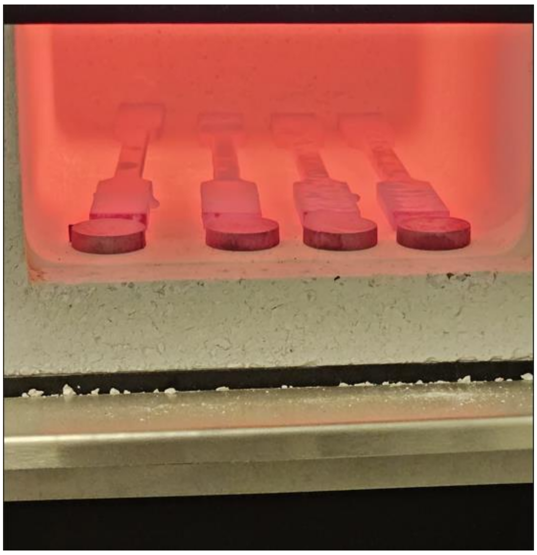
- TTT (Time Temperature Transformation) Diagram.



- After heat treatment process X ray results in the machine

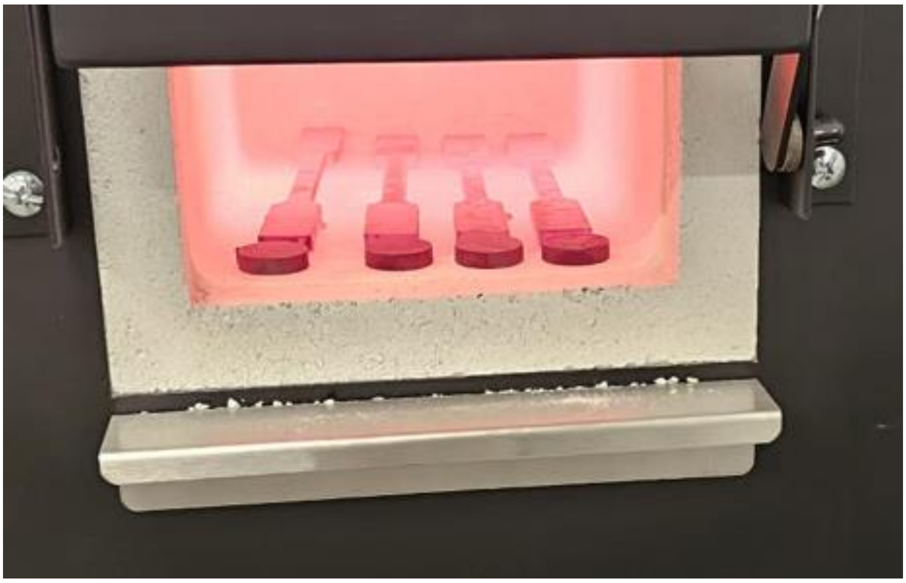
- Prepared samples

- Annealing Heat treatment process and results

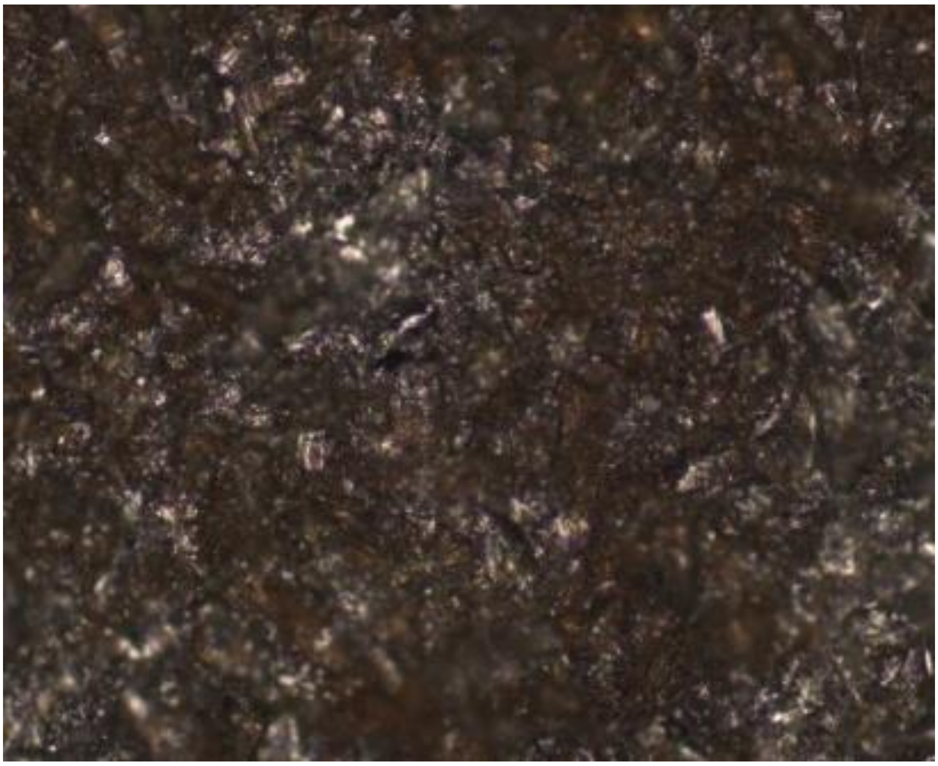


- Normalising heat treatment in the furnace and results

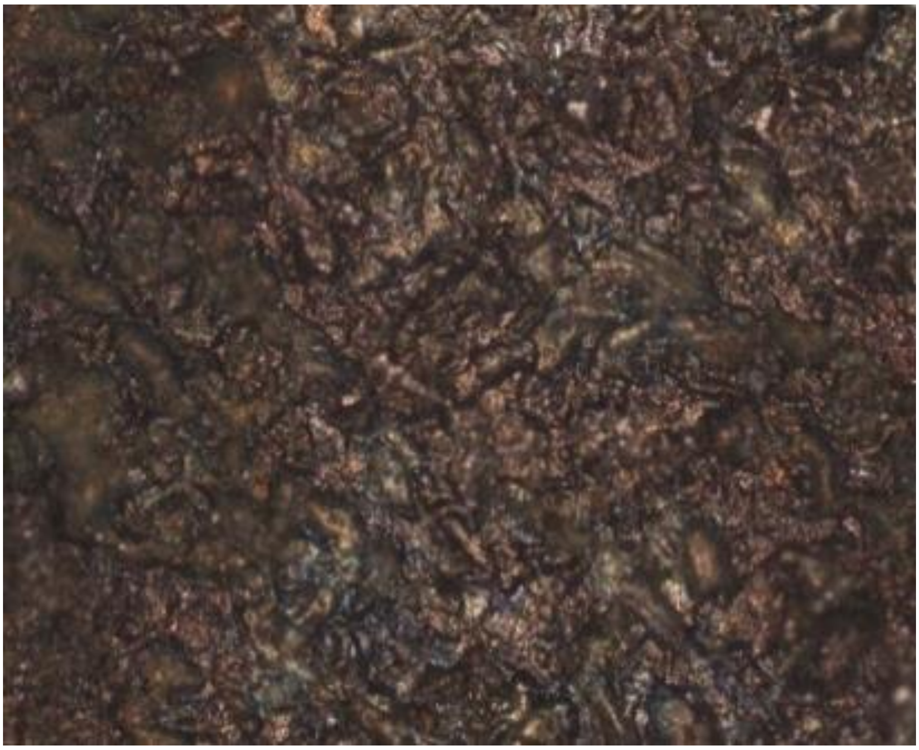
- Quenching in water heat treatment process and results



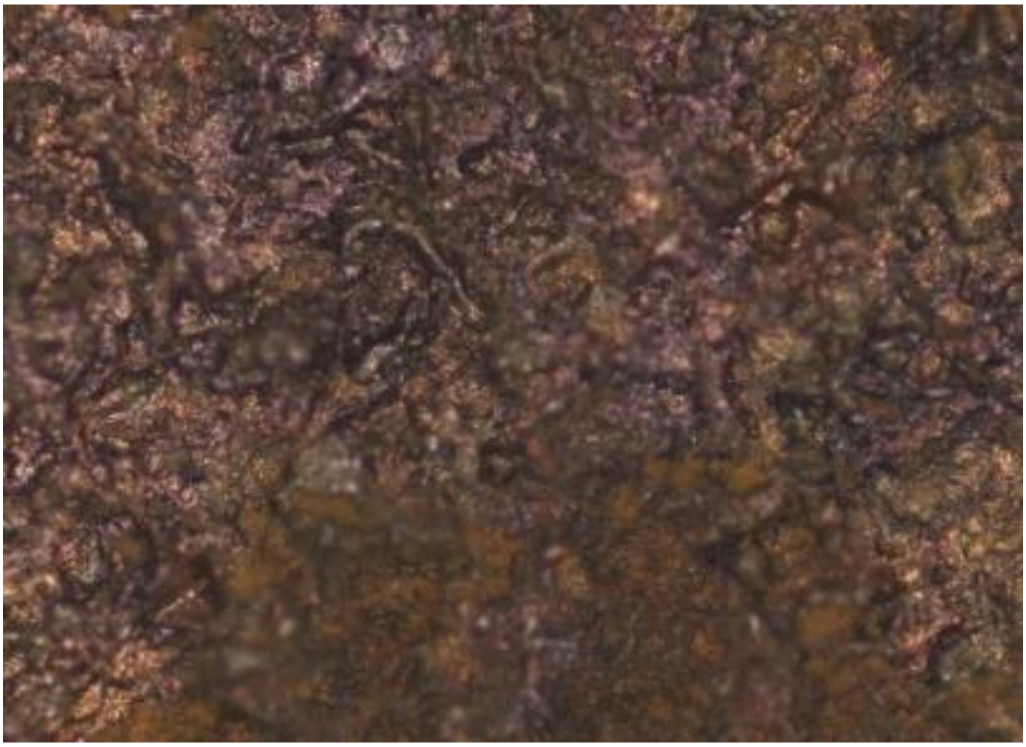
- Microscopic Examination
  - Annealing Treated samples



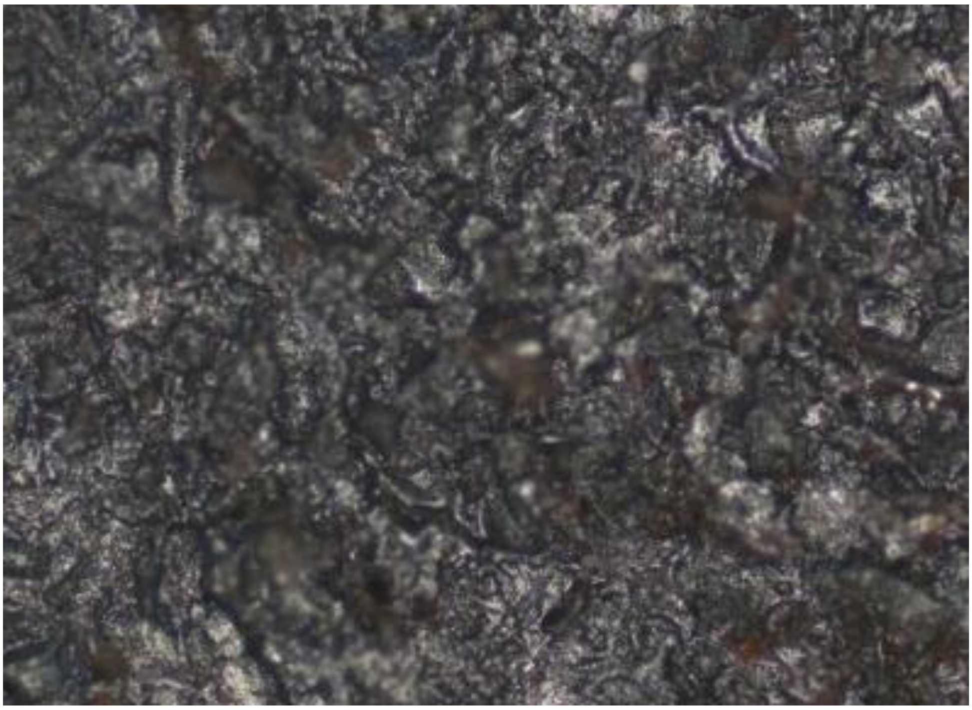
  - Normalising Treated samples



  - Quenching in water treated samples

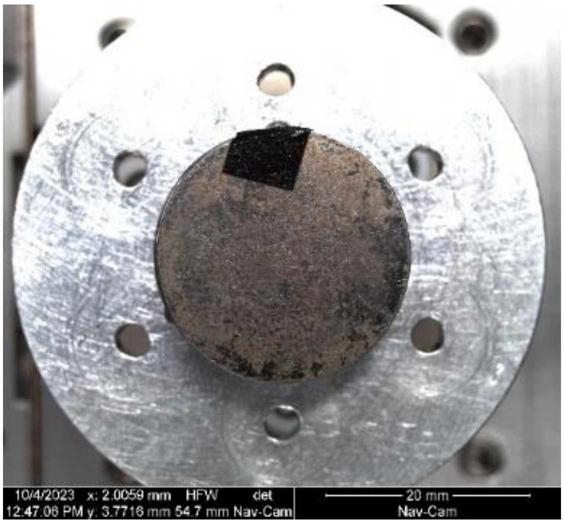


- Sand blasting samples

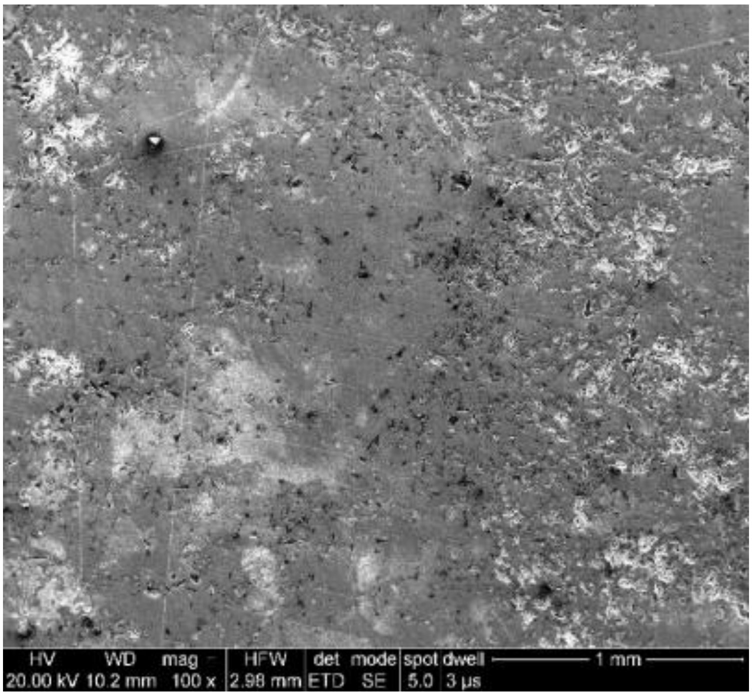


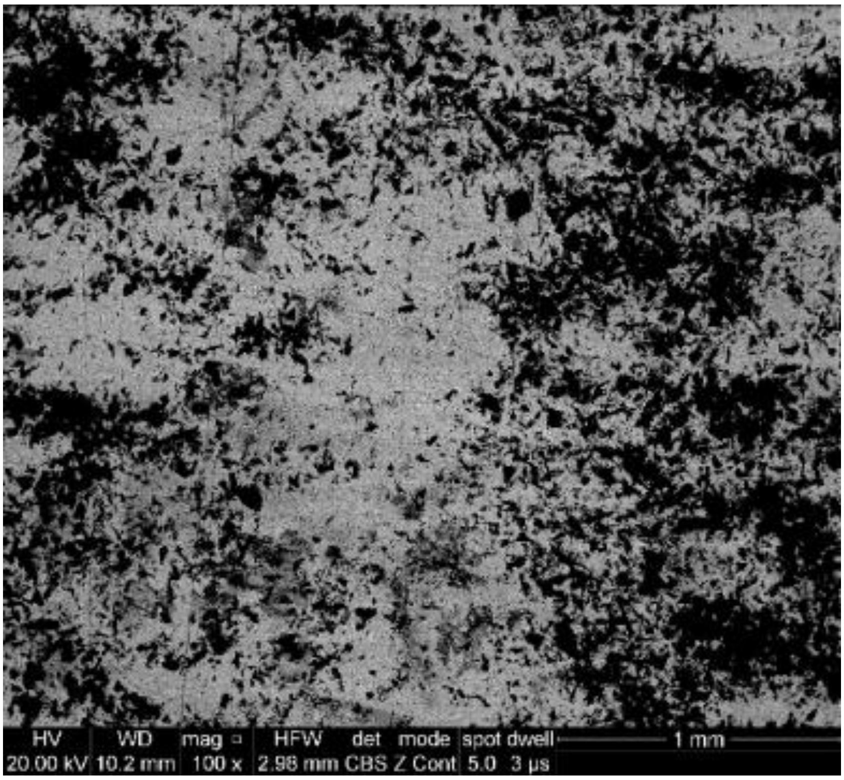
- Untreated samples

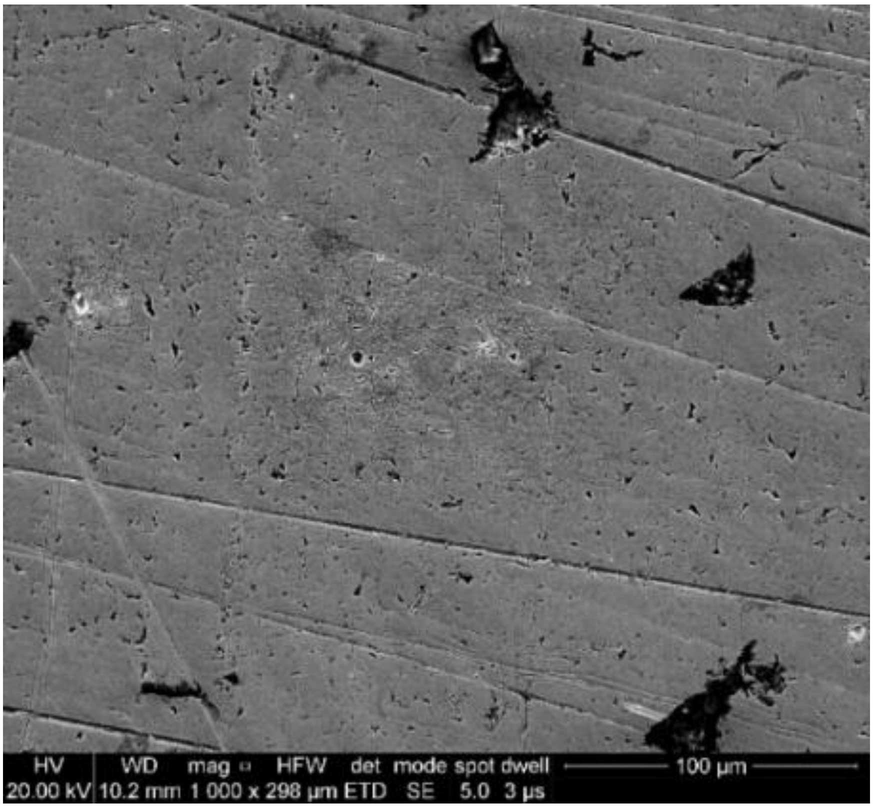
- Samples in SEM machine

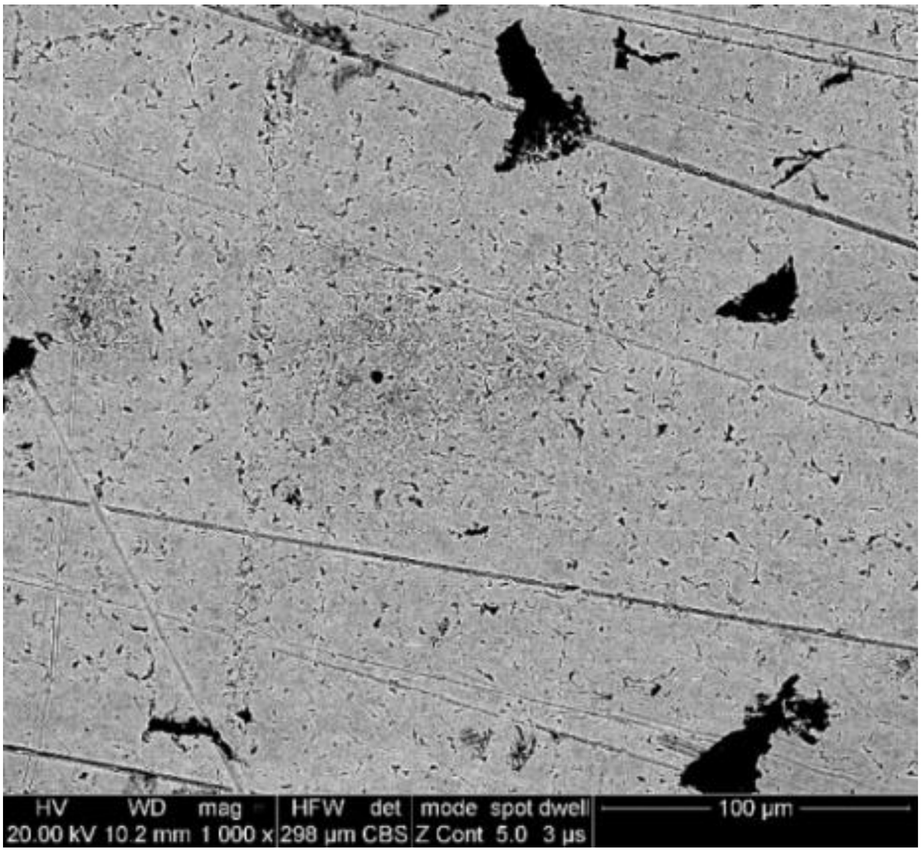


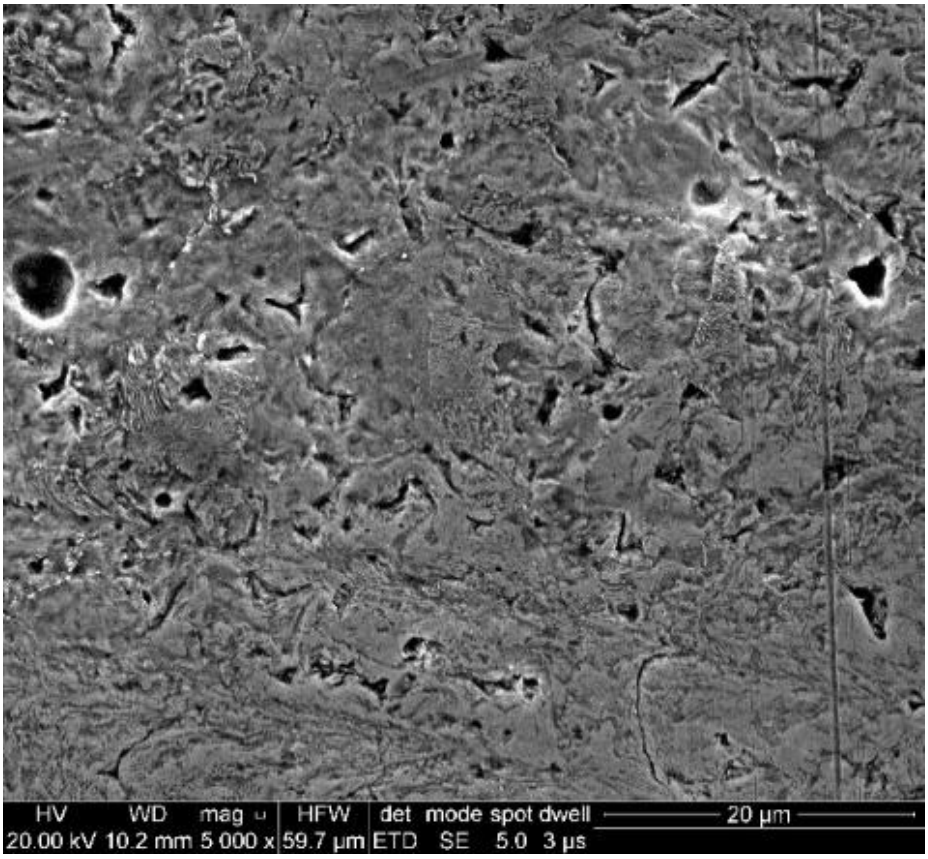
- SEM Results

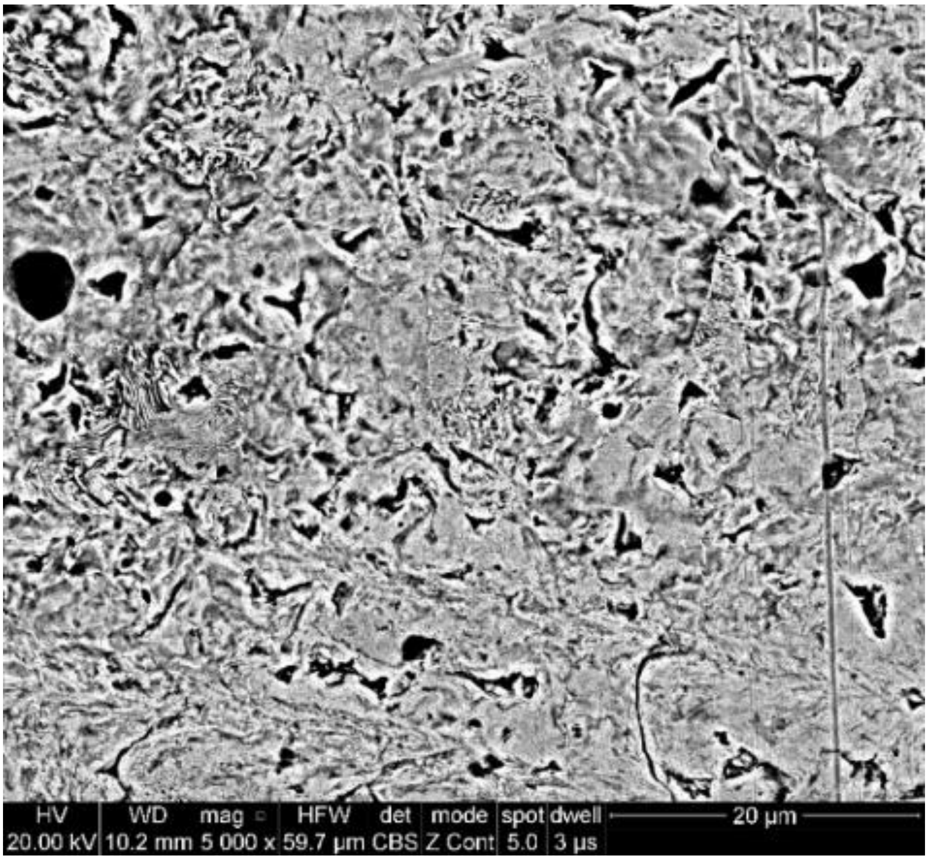

HV WD mag HFW det mode spot dwell
20.00 kV 10.2 mm 100 x 2.98 mm ETD SE 5.0 3 µs
1 mm

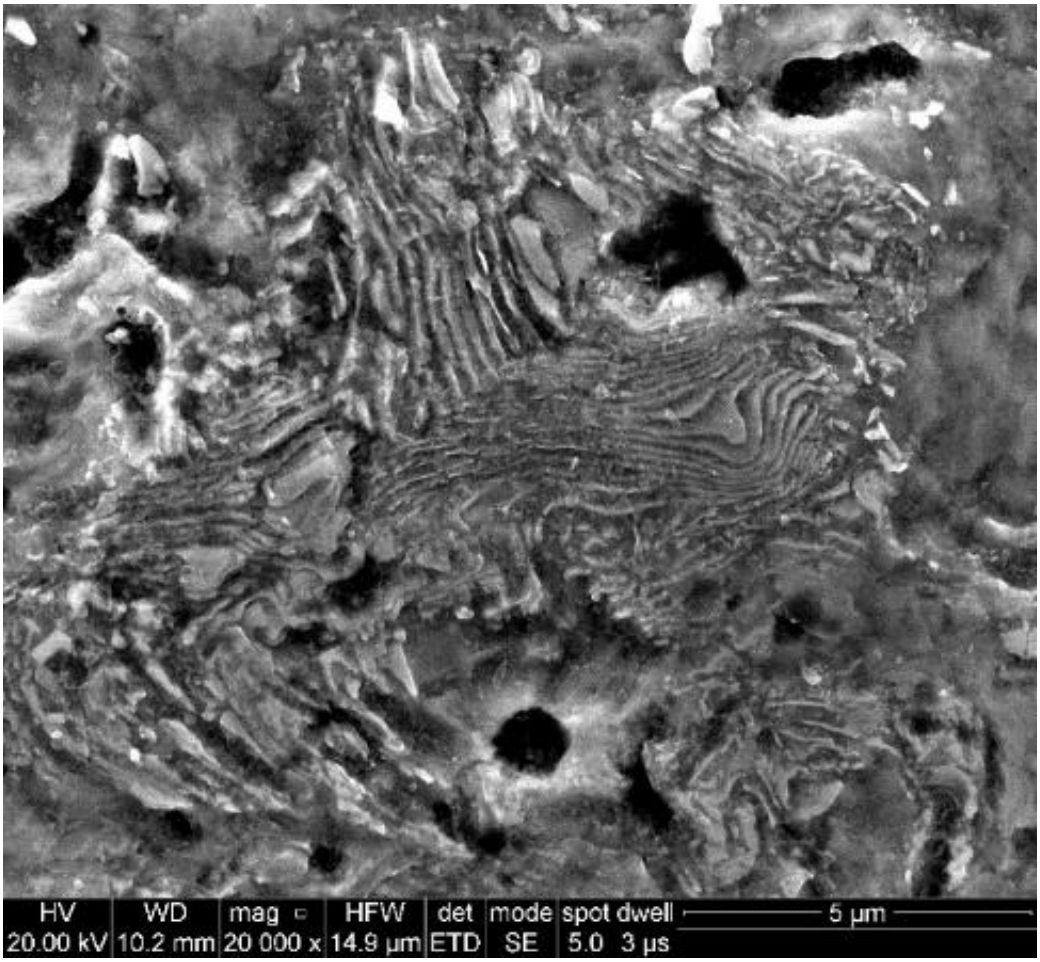

HV WD mag HFW det mode spot dwell
20.00 kV 10.2 mm 100 x 2.98 mm CBS Z Cont 5.0 3 µs
1 mm

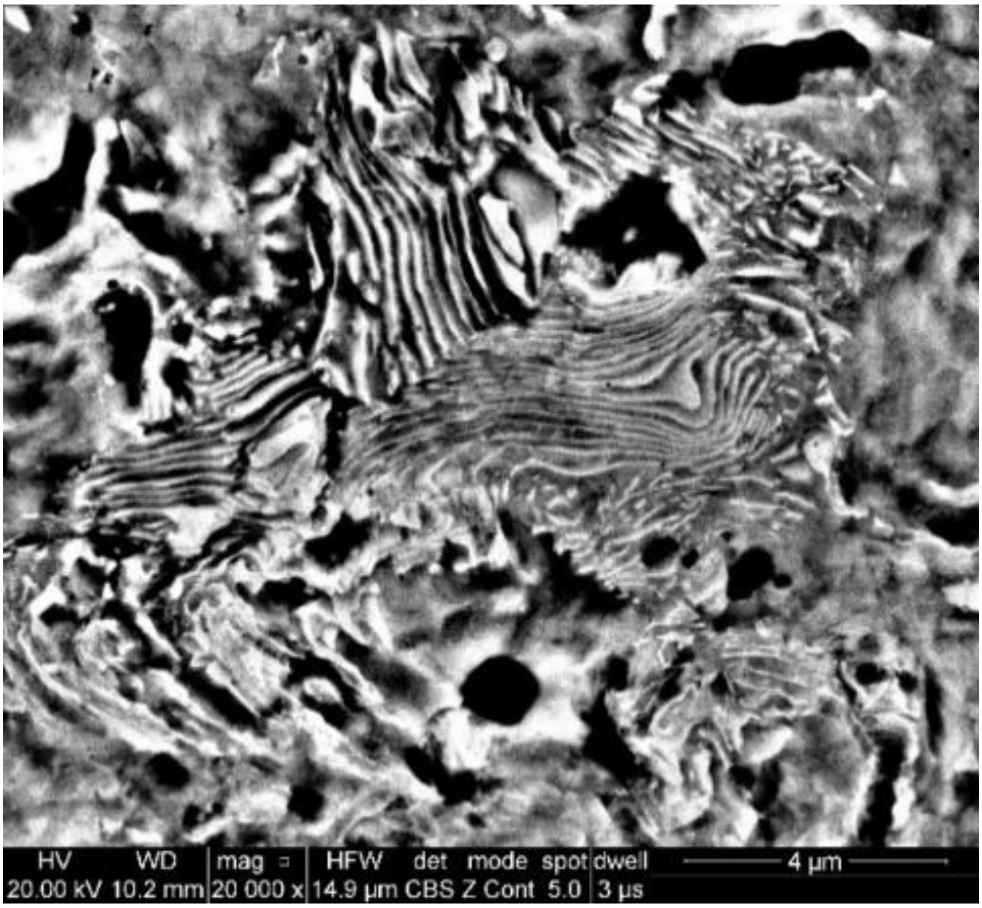

HV WD mag HFW det mode spot dwell
20.00 kV 10.2 mm 1 000 x 298 µm ETD SE 5.0 3 µs
100 µm

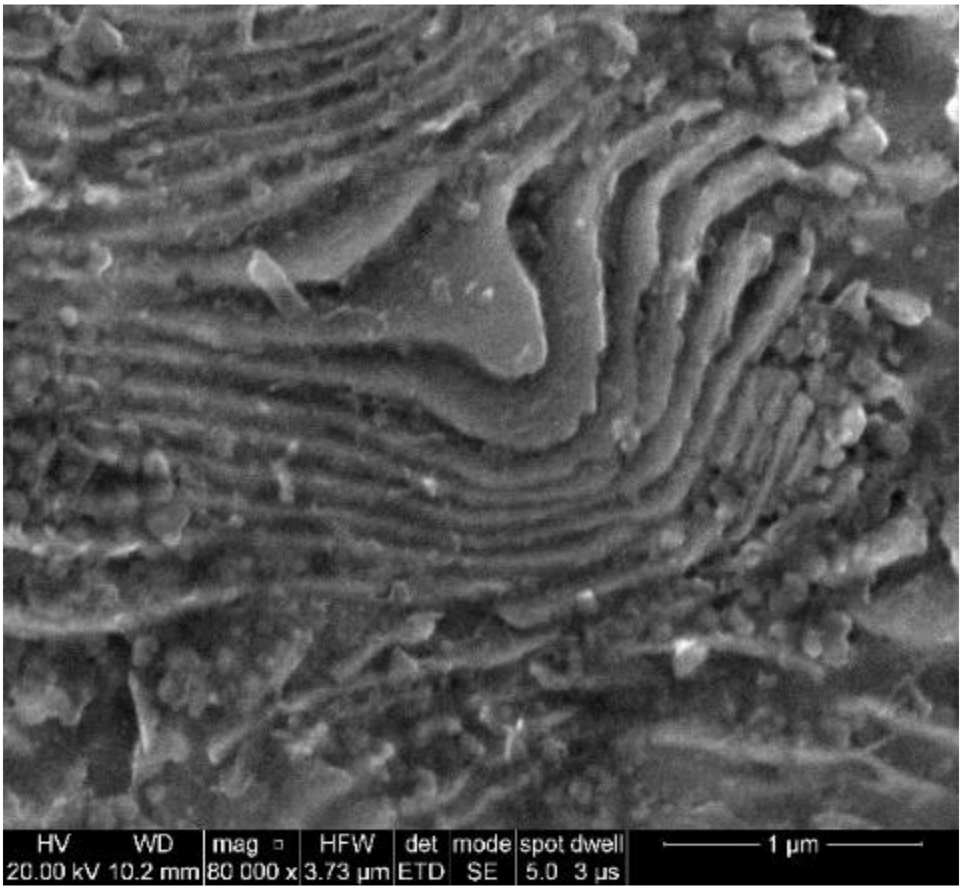

HV WD mag HFW det mode spot dwell
20.00 kV 10.2 mm 1 000 x 298 µm CBS Z Cont 5.0 3 µs
100 µm

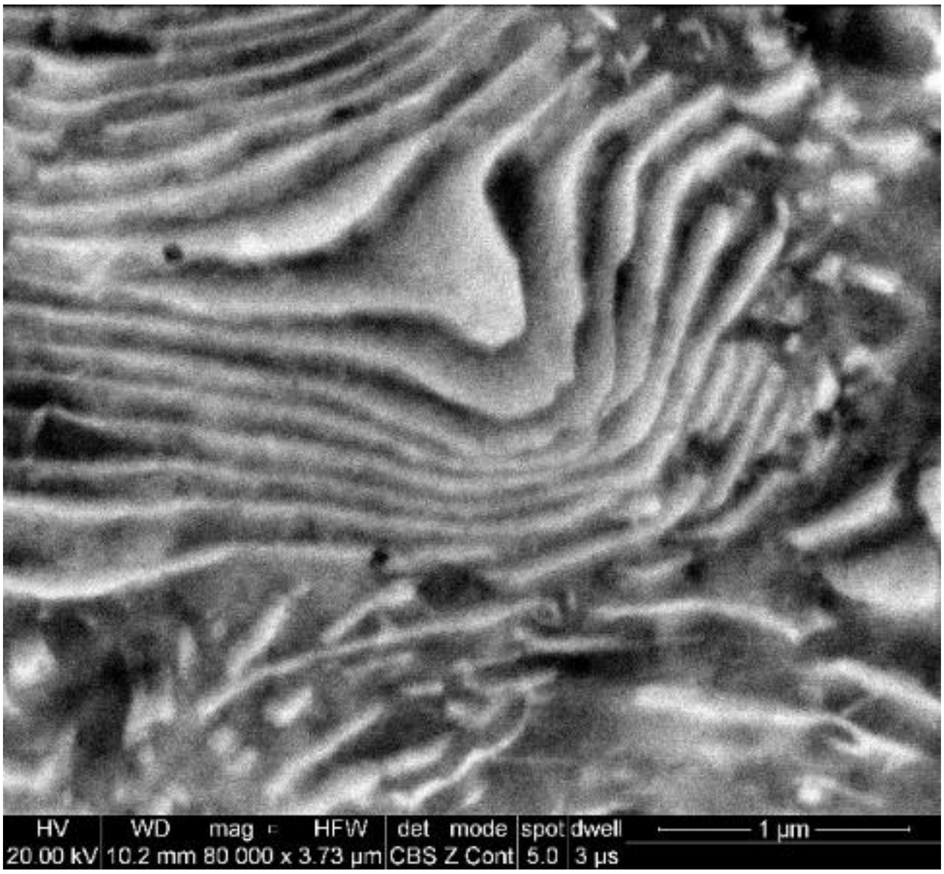

HV
WD
mag
HFW
det
mode
spot
dwell
20 µm
20.00 kV
10.2 mm
5 000 x
59.7 µm
ETD
SE
5.0
3 µs


HV
WD
mag
HFW
det
mode
spot
dwell
20 µm
20.00 kV
10.2 mm
5 000 x
59.7 µm
CBS
Z Cont
5.0
3 µs

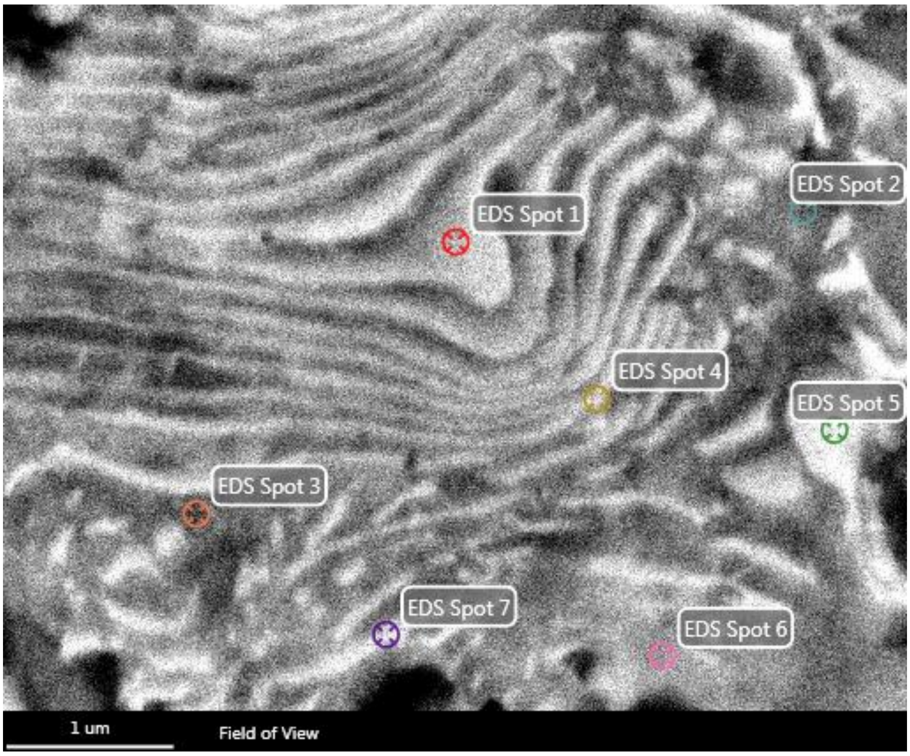

HV
WD
mag
HFW
det
mode
spot
dwell
5 µm
20.00 kV
10.2 mm
20 000 x
14.9 µm
ETD
SE
5.0
3 µs


HV
WD
mag
HFW
det
mode
spot
dwell
4 µm
20.00 kV
10.2 mm
20 000 x
14.9 µm
CBS
Z Cont
5.0
3 µs

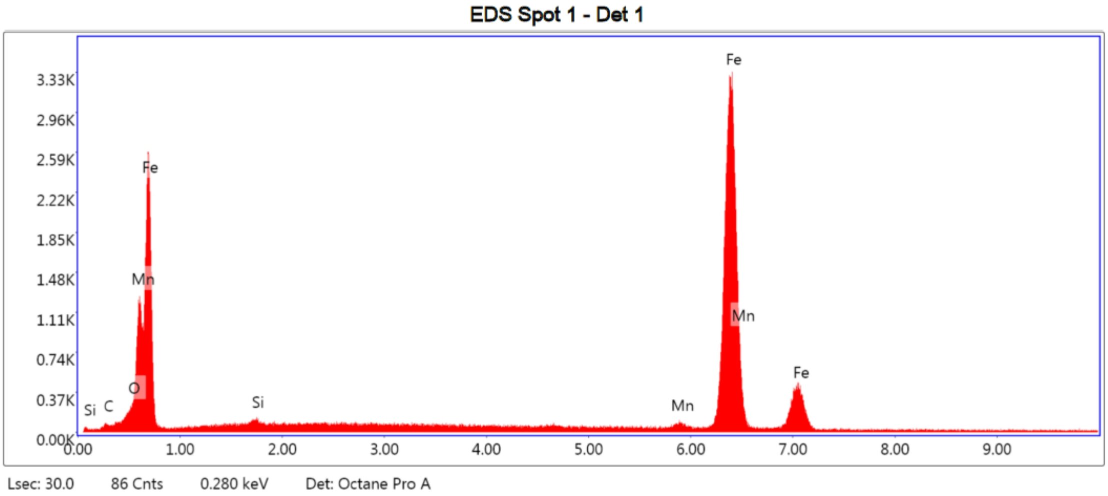

HV
20.00 kV
WD
10.2 mm
mag
80 000 x
HFW
3.73 µm
det
ETD
mode
SE
spot
5.0
dwell
3 µs
1 µm


HV
20.00 kV
WD
10.2 mm
mag
80 000 x
HFW
3.73 µm
det
CBS
mode
Z Cont
spot
5.0
dwell
3 µs
1 µm

- EDX results



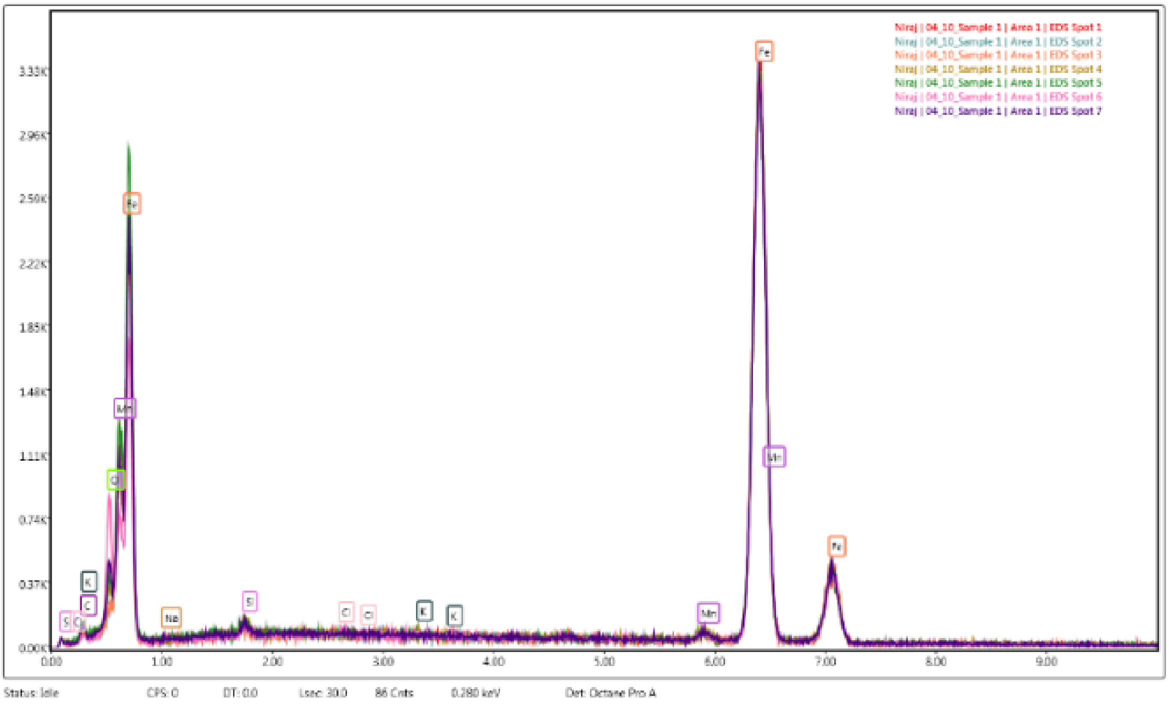
- Spot 1 result



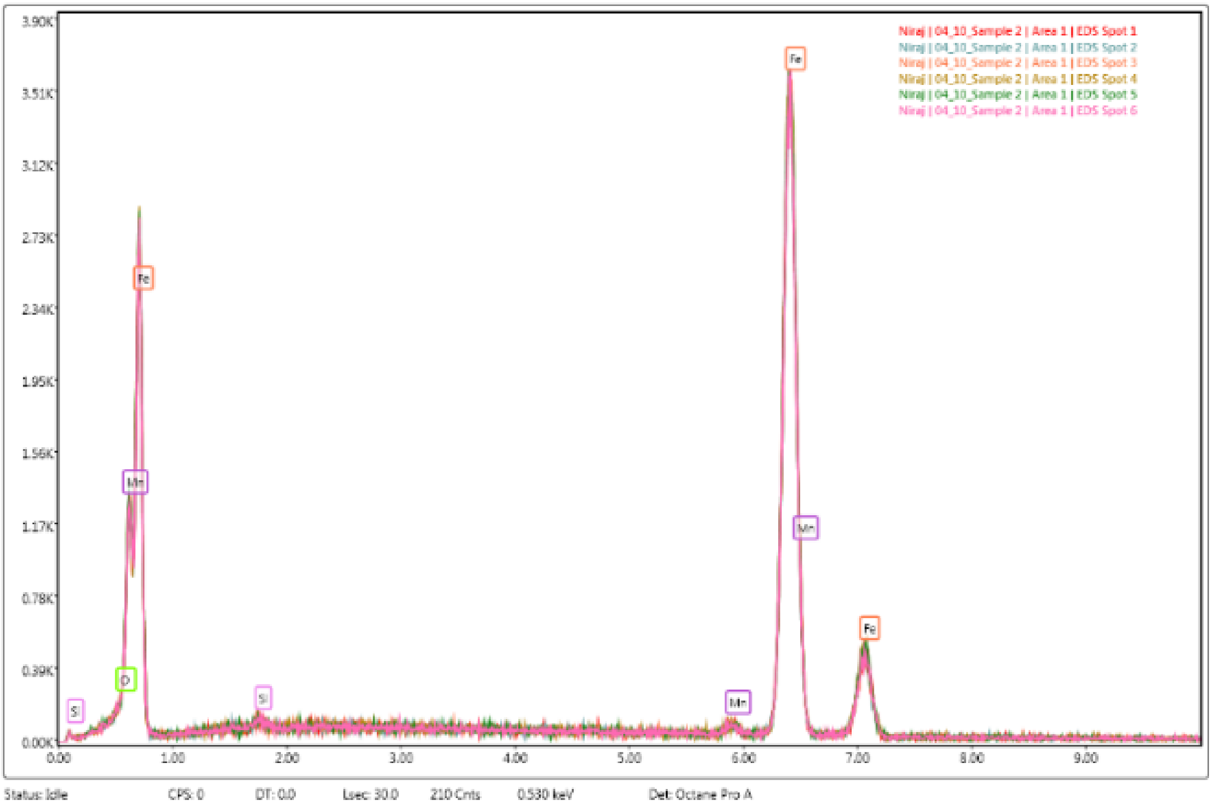
eZAF Smart Quant Results

Element	Weight %	Atomic %	Net Int.	Error %	Kratio	Z	A	F
C K	0.38	1.67	3.33	76.89	0.0010	1.3133	0.2091	1.0000
O K	1.36	4.52	61.56	12.94	0.0078	1.2636	0.4527	1.0000
SiK	0.42	0.79	24.07	30.29	0.0022	1.1613	0.4516	1.0029
MnK	1.22	1.18	48.31	18.22	0.0135	0.9770	0.9960	1.1328
FeK	96.62	91.84	3045.12	1.78	0.9606	0.9939	1.0002	1.0002

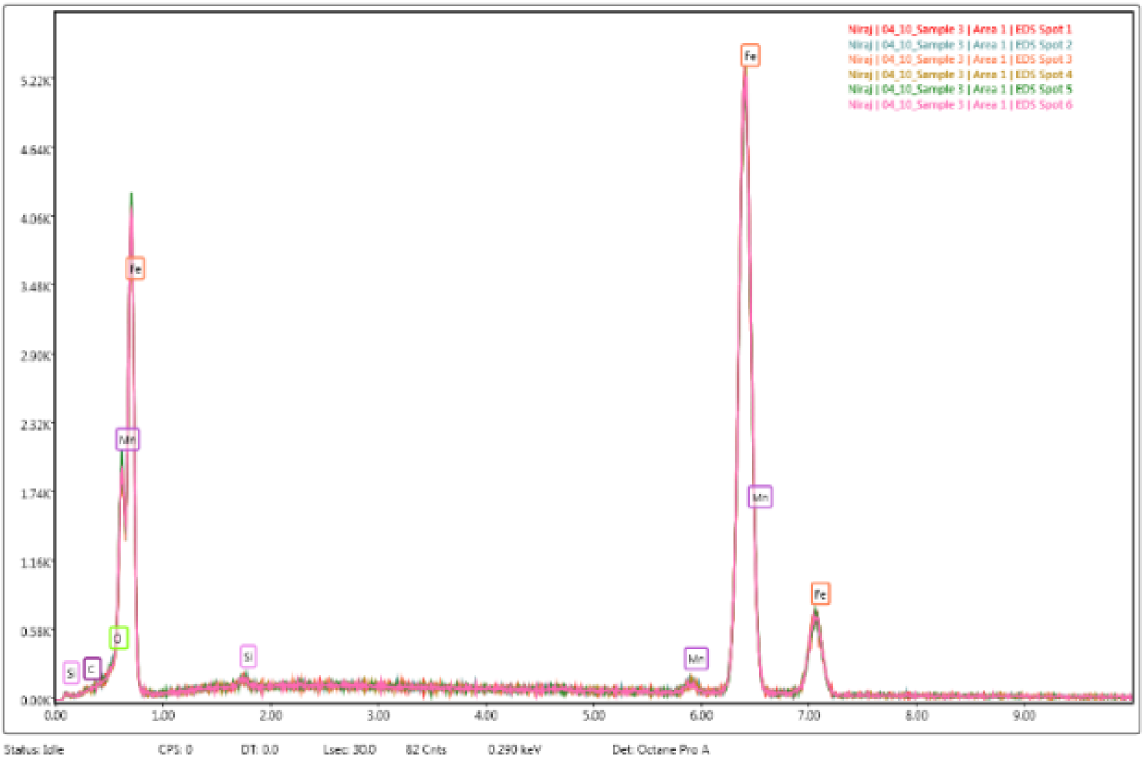
- Annealing treated samples SEM Results



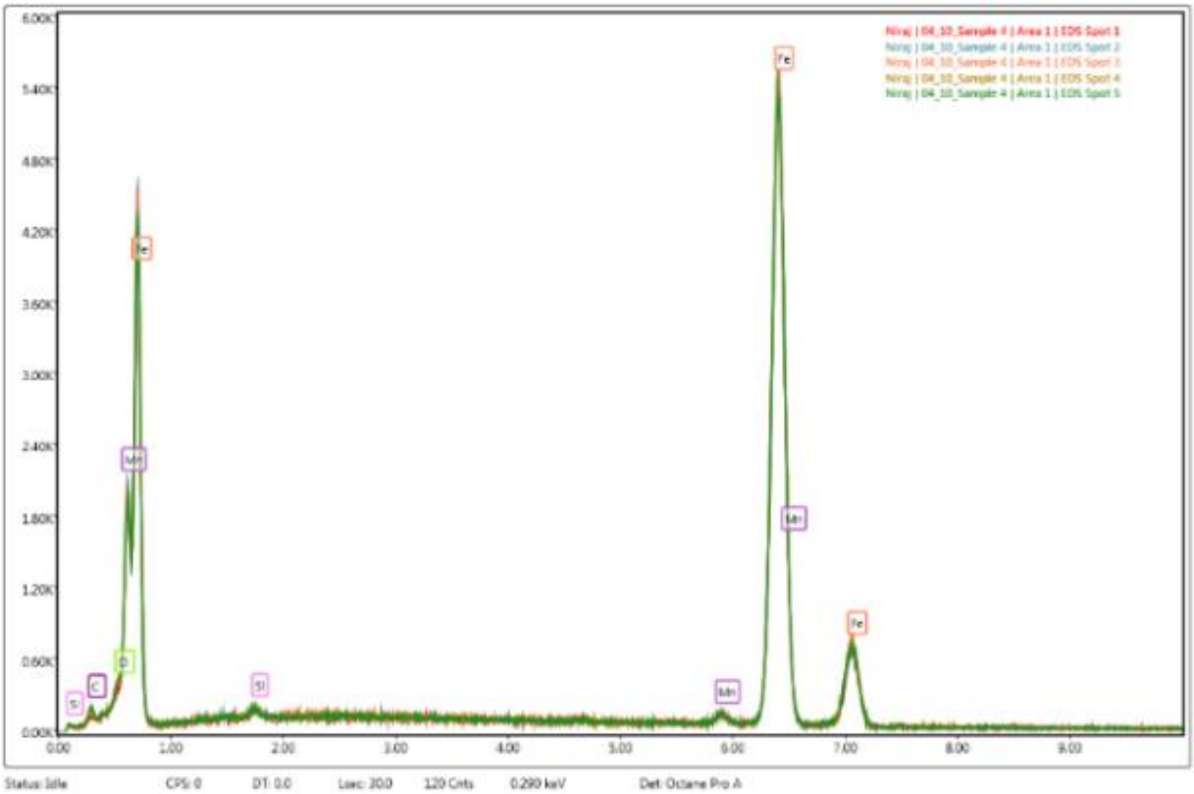
- Normalising treated samples SEM results



- Quenching in water treated samples SEM results



- Untreated samples SEM results

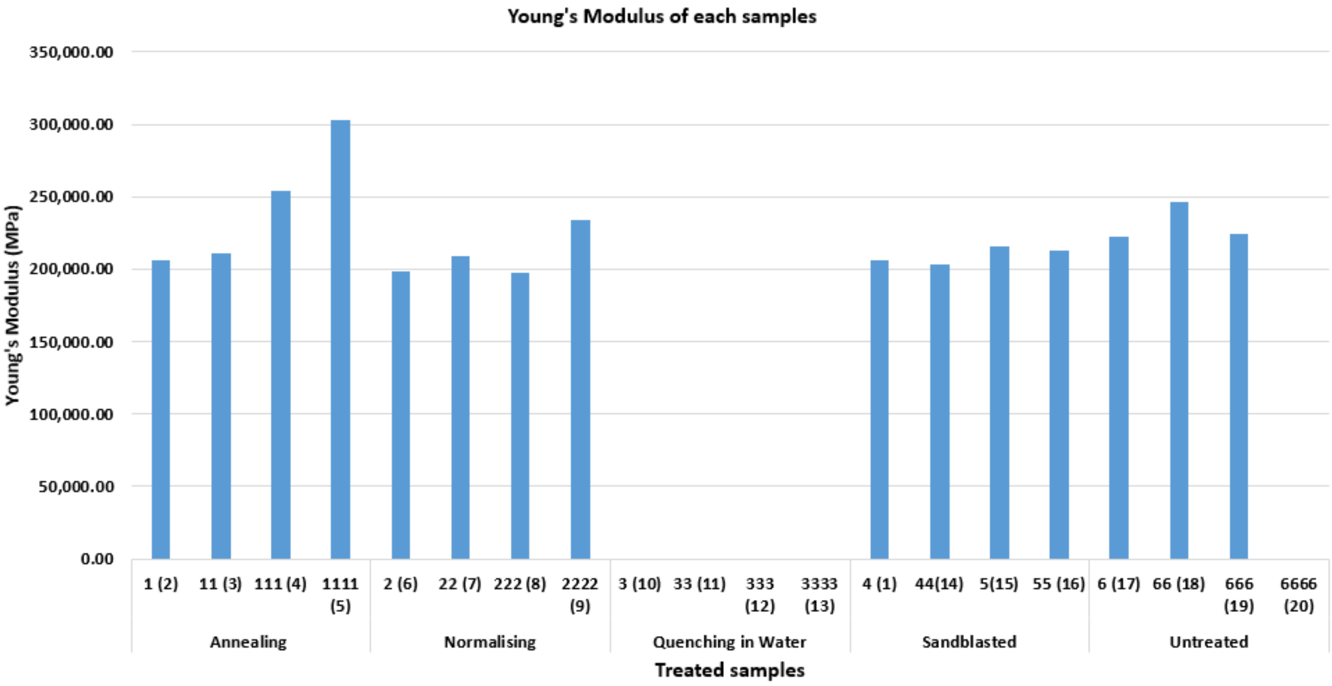


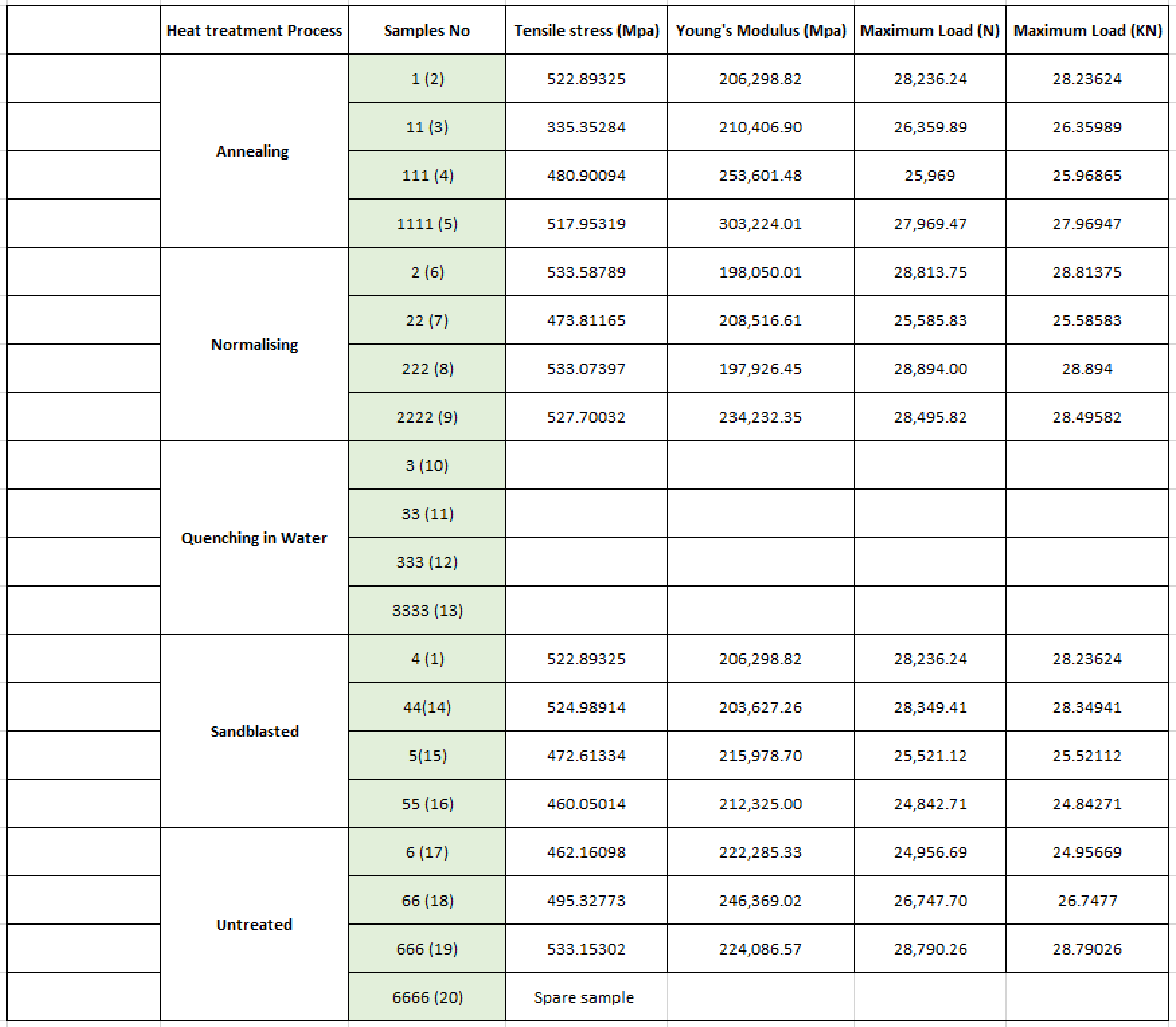
- Tensile testing Results

- Table for identification of tensile tested samples

Sr No	Test	DB Test specimen 1	DB Test specimen 2	DB Test specimen 3	DB Test specimen 4
1	Annealing	1 (2)	11 (3)	111 (4)	1111 (5)
2	Normelising	2 (6)	22 (7)	222 (8)	2222 (9)
3	Quanching in Water	3 (10)	33 (11)	333 (12)	3333 (13)
4	Sand blasted	4 (1)	44 (14)	5 (15)	55 (16)
5	Untreated + send blasted	6 (17)	66 (18)	666 (19)	6666 (20)

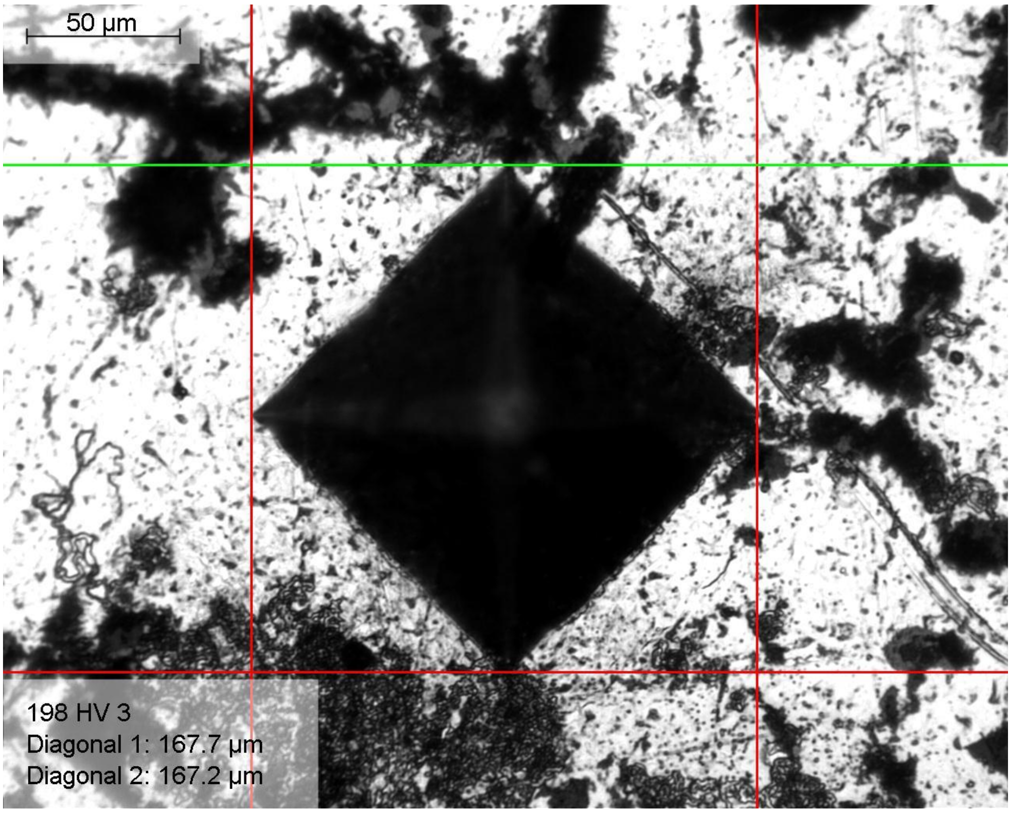
- Youngs modulus from all excel sheet

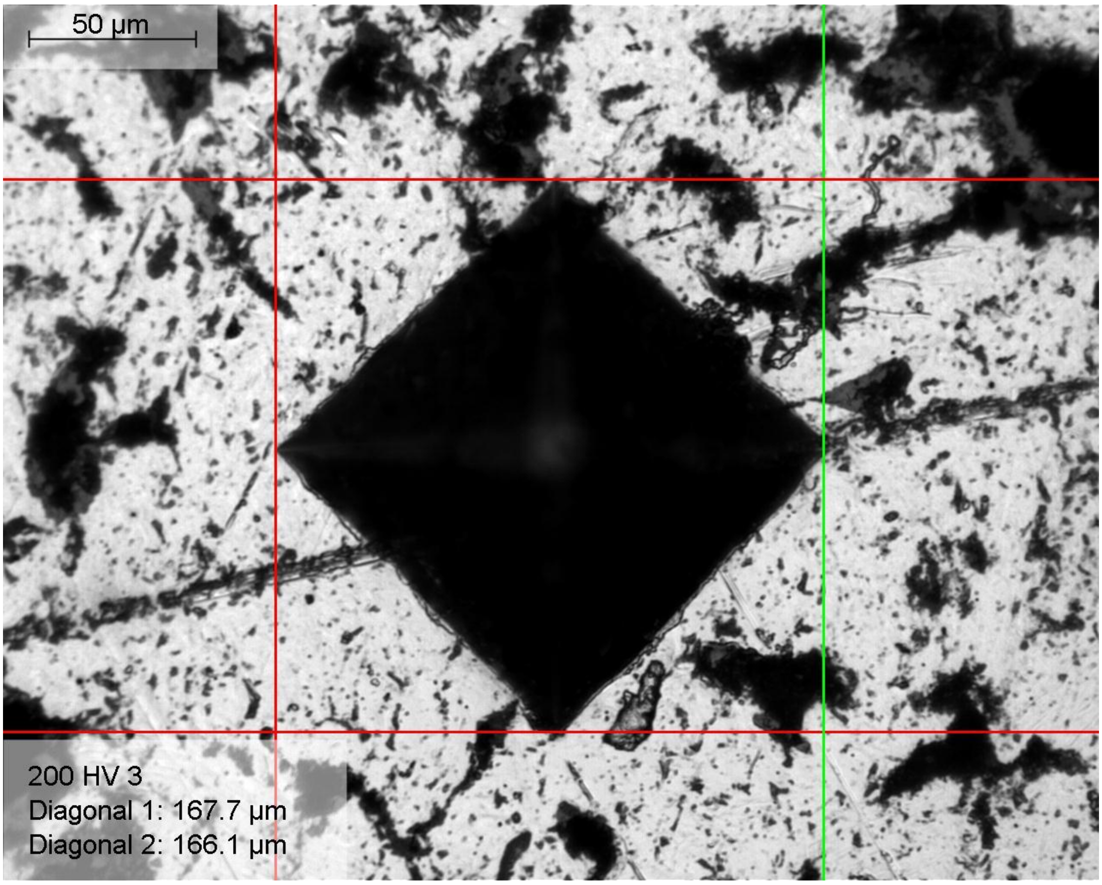


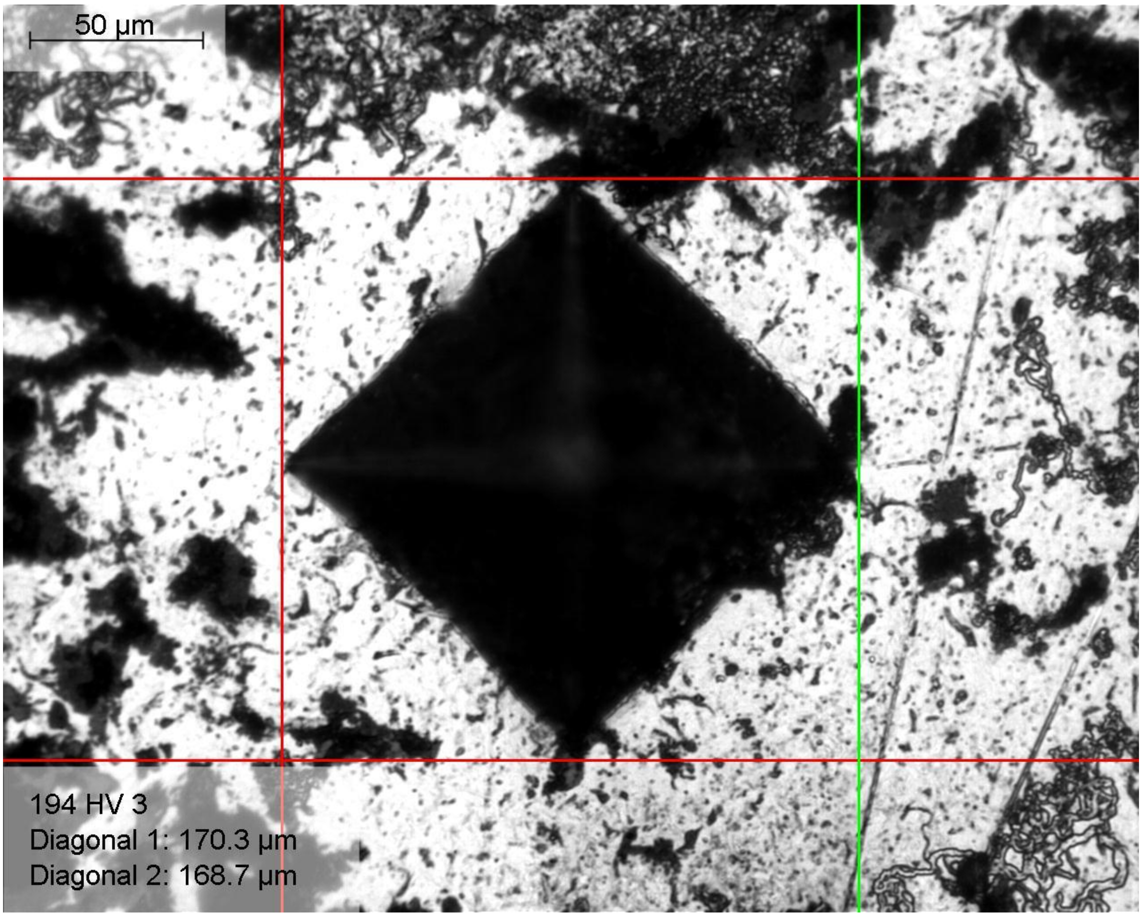


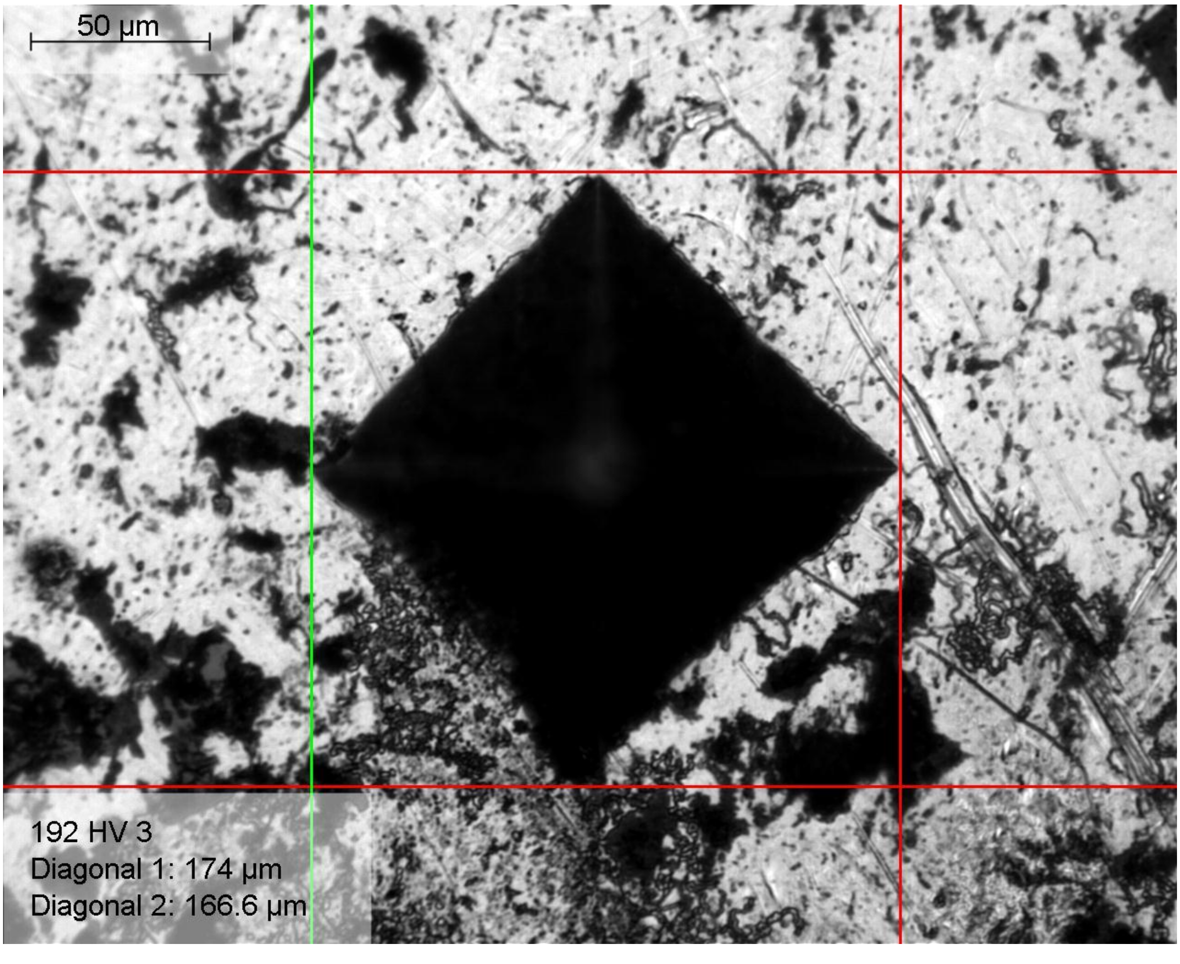
	Heat treatment Process	Samples No	Tensile stress (Mpa)	Young's Modulus (Mpa)	Maximum Load (N)	Maximum Load (KN)
	Annealing	1 (2)	522.89325	206,298.82	28,236.24	28.23624
		11 (3)	335.35284	210,406.90	26,359.89	26.35989
		111 (4)	480.90094	253,601.48	25,969	25.96865
		1111 (5)	517.95319	303,224.01	27,969.47	27.96947
	Normalising	2 (6)	533.58789	198,050.01	28,813.75	28.81375
		22 (7)	473.81165	208,516.61	25,585.83	25.58583
		222 (8)	533.07397	197,926.45	28,894.00	28.894
		2222 (9)	527.70032	234,232.35	28,495.82	28.49582
	Quenching in Water	3 (10)				
		33 (11)				
		333 (12)				
		3333 (13)				
	Sandblasted	4 (1)	522.89325	206,298.82	28,236.24	28.23624
		44(14)	524.98914	203,627.26	28,349.41	28.34941
		5(15)	472.61334	215,978.70	25,521.12	25.52112
		55 (16)	460.05014	212,325.00	24,842.71	24.84271
	Untreated	6 (17)	462.16098	222,285.33	24,956.69	24.95669
		66 (18)	495.32773	246,369.02	26,747.70	26.7477
		666 (19)	533.15302	224,086.57	28,790.26	28.79026
		6666 (20)	Spare sample			

- Hardness testing Results
    - Annealing treated 4 mean samples results

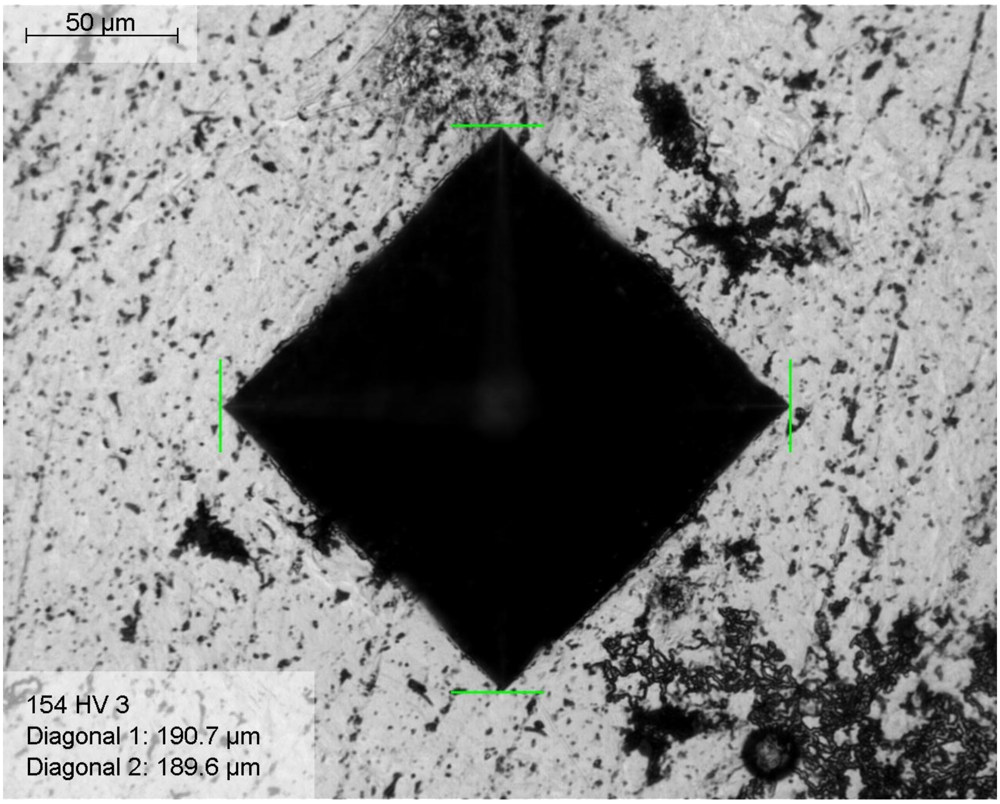


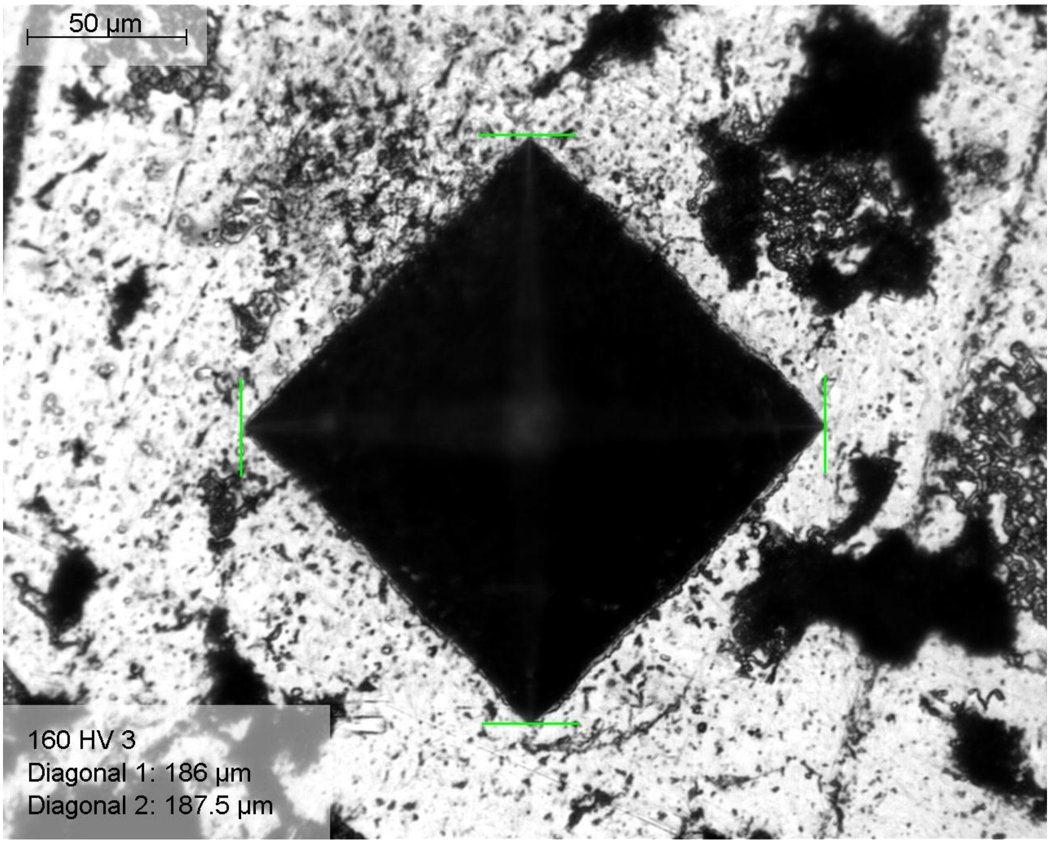


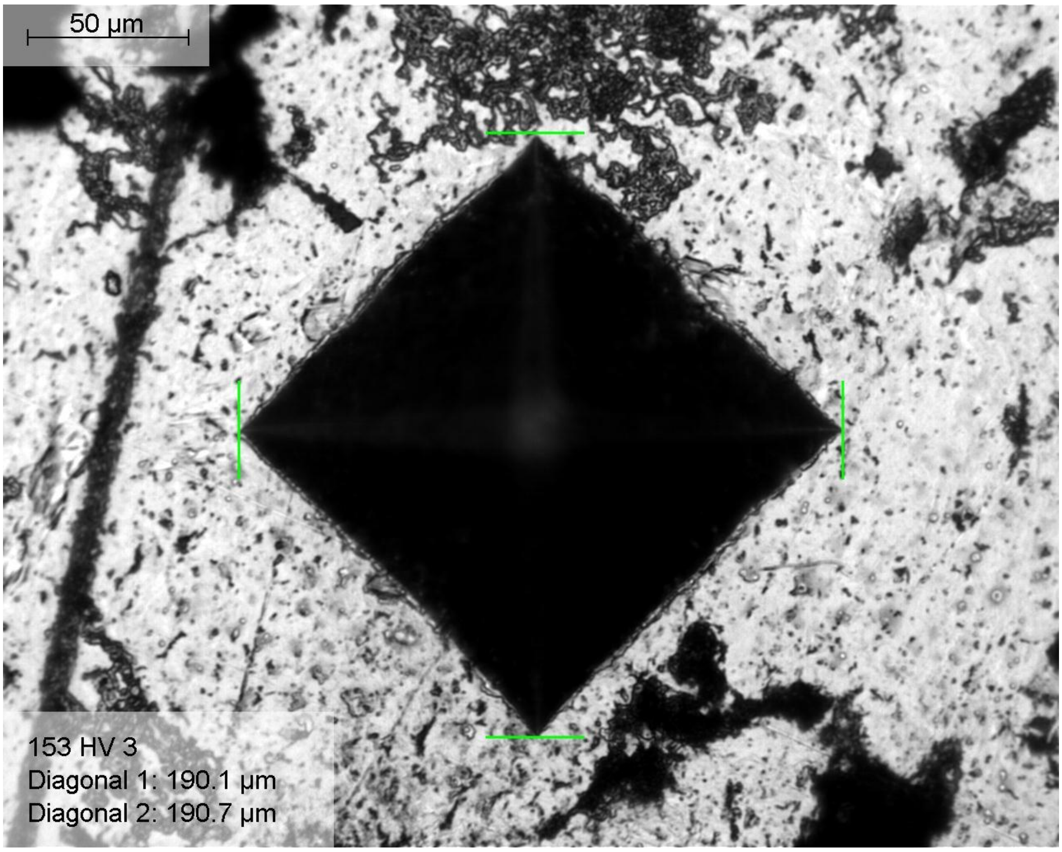

50 µm
194 HV 3
Diagonal 1: 170.3 µm
Diagonal 2: 168.7 µm

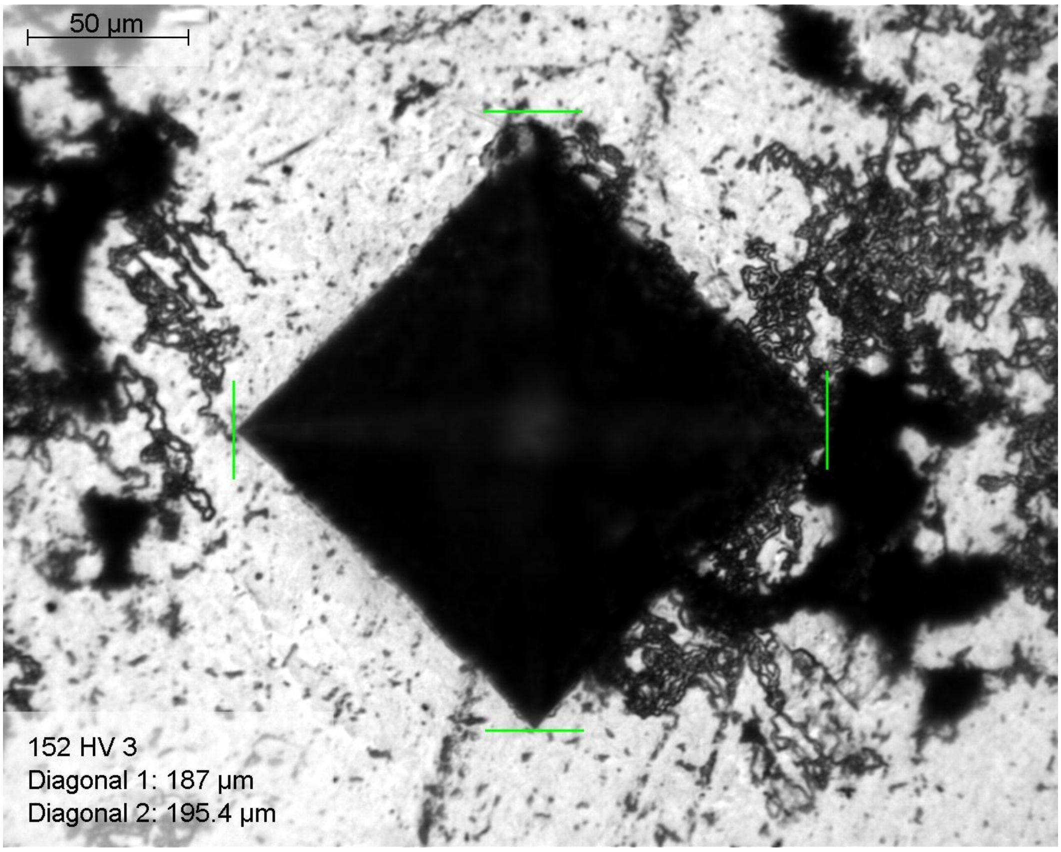

50 µm
192 HV 3
Diagonal 1: 174 µm
Diagonal 2: 166.6 µm

- Normalising treated 4 mean samples results

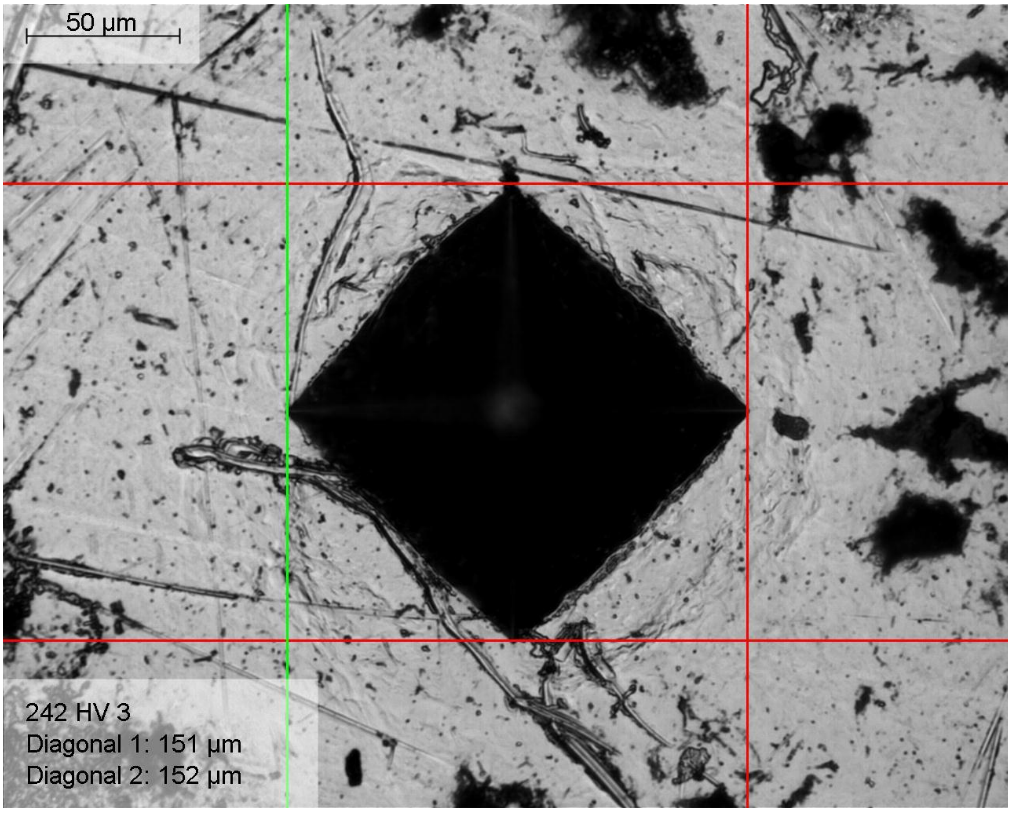


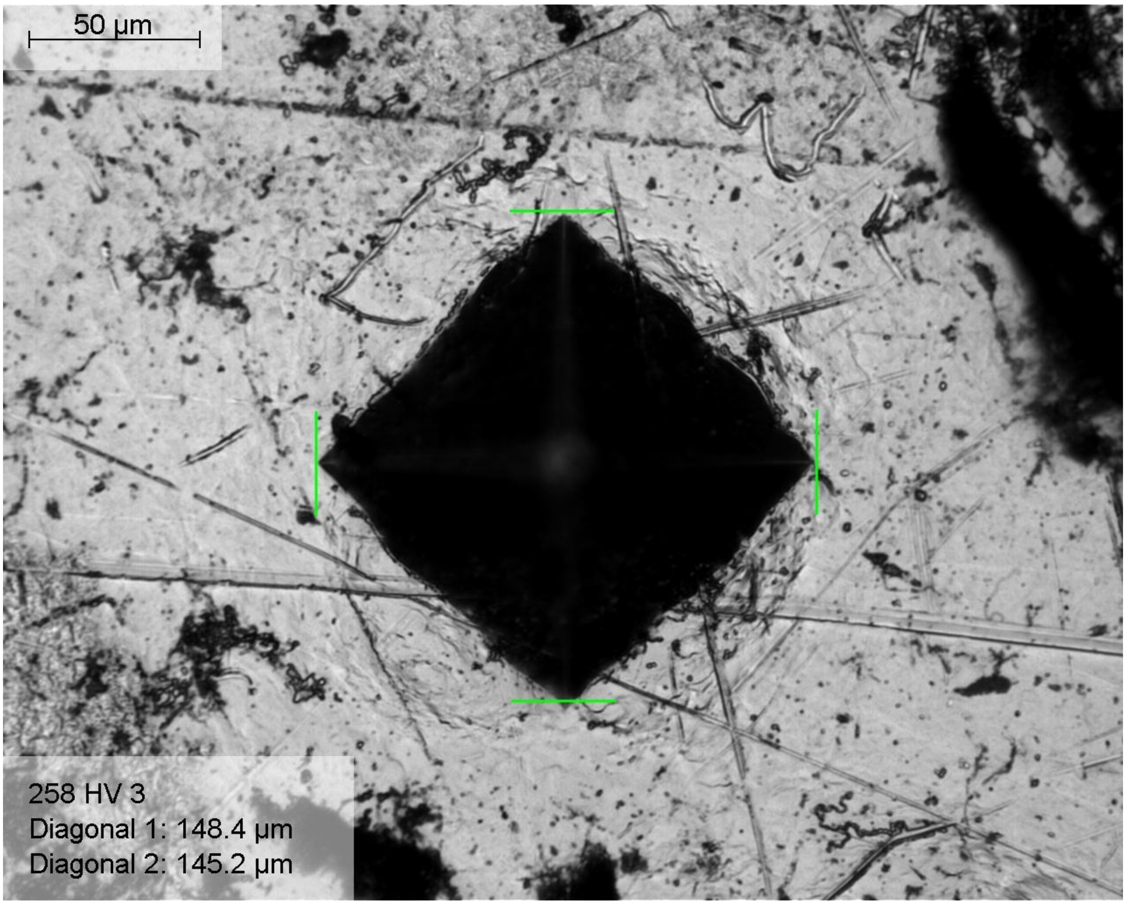


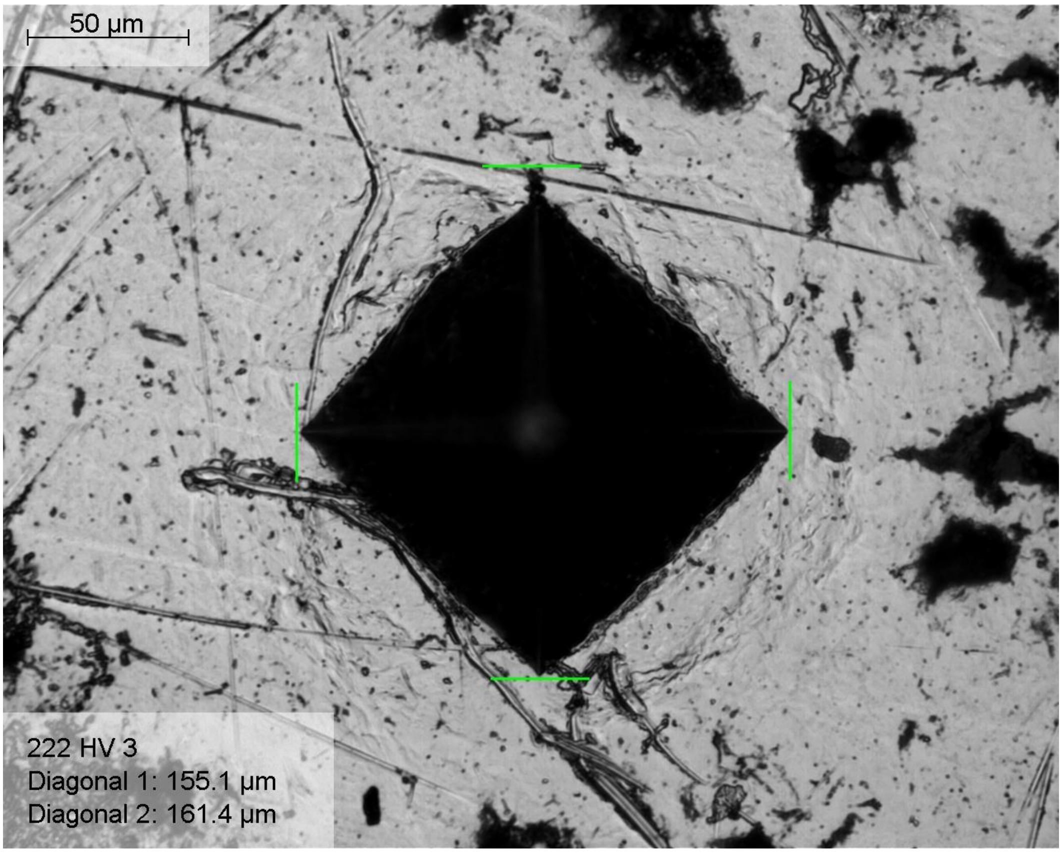

50 µm
153 HV 3
Diagonal 1: 190.1 µm
Diagonal 2: 190.7 µm

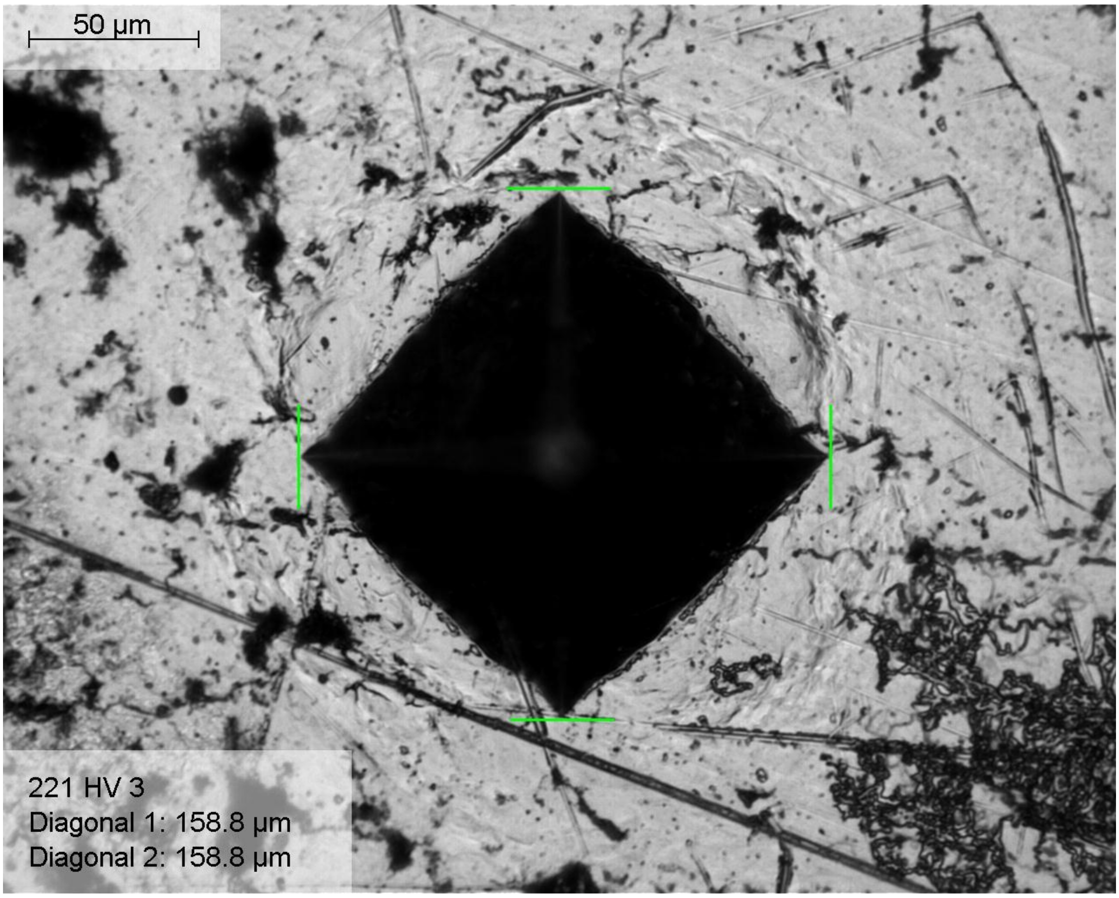

50 µm
152 HV 3
Diagonal 1: 187 µm
Diagonal 2: 195.4 µm

- Quenching in water treated 4 mean samples results

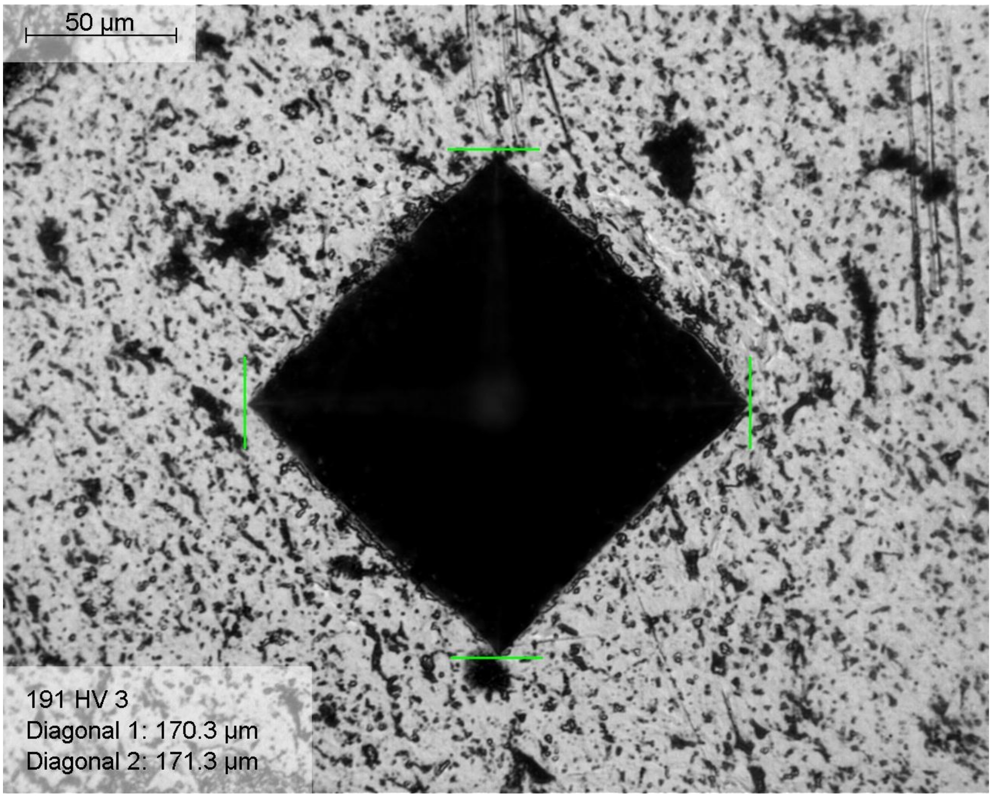


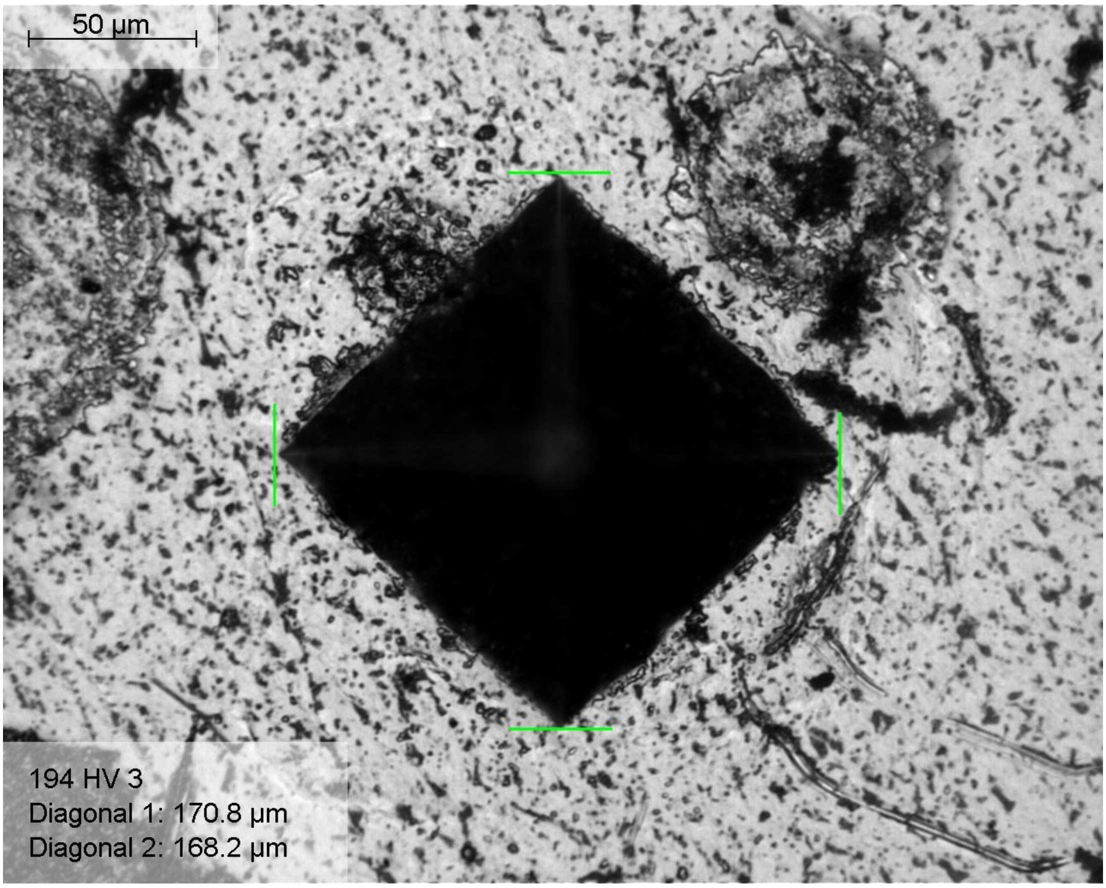



50 µm
222 HV 3
Diagonal 1: 155.1 µm
Diagonal 2: 161.4 µm

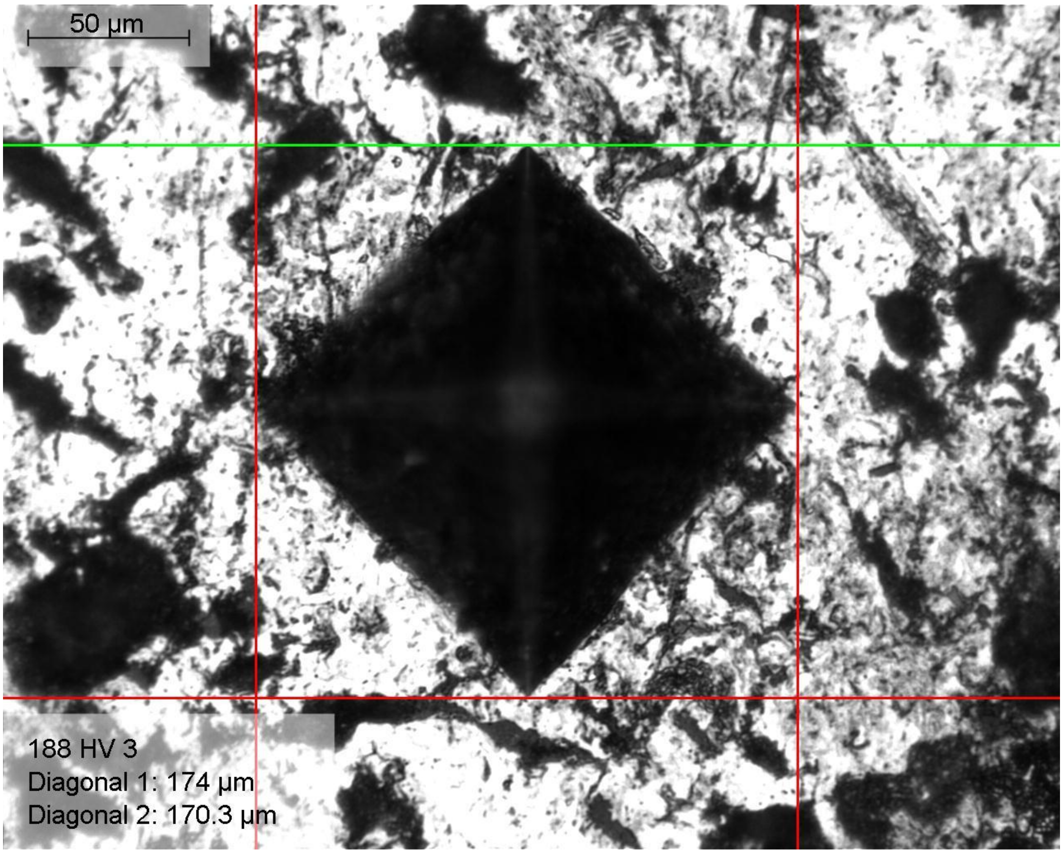

50 µm
221 HV 3
Diagonal 1: 158.8 µm
Diagonal 2: 158.8 µm

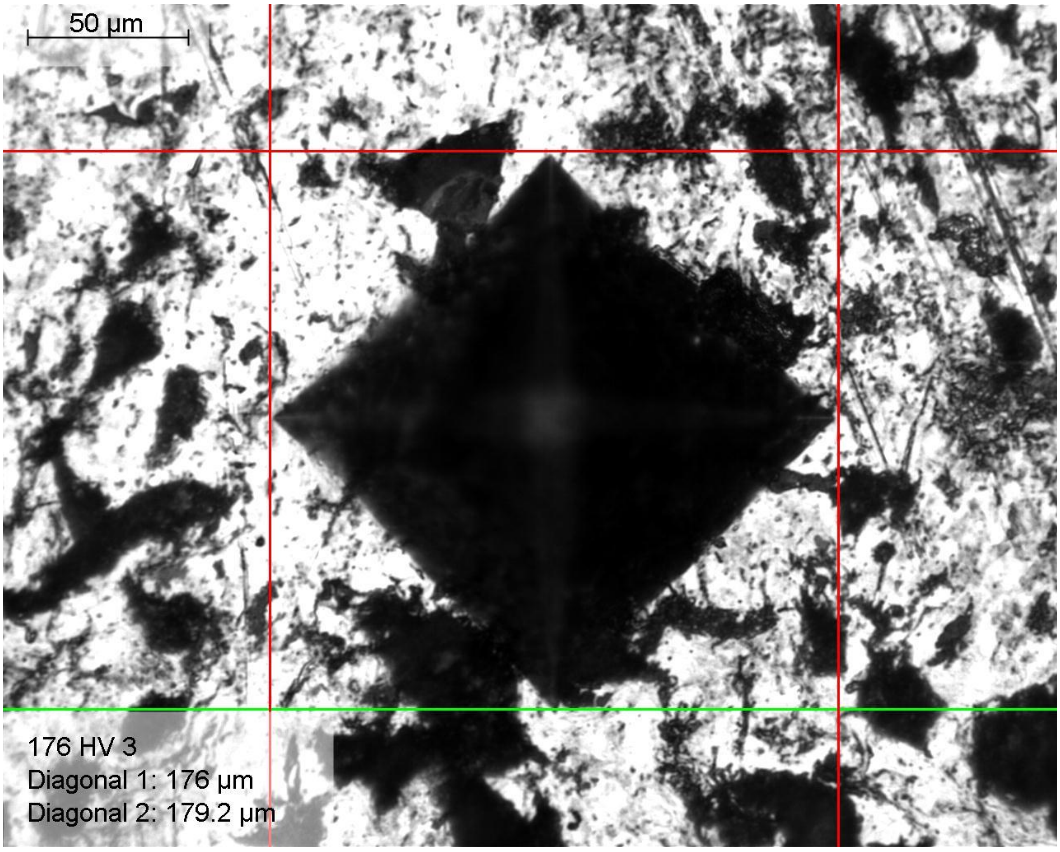
- Sand blasted samples results





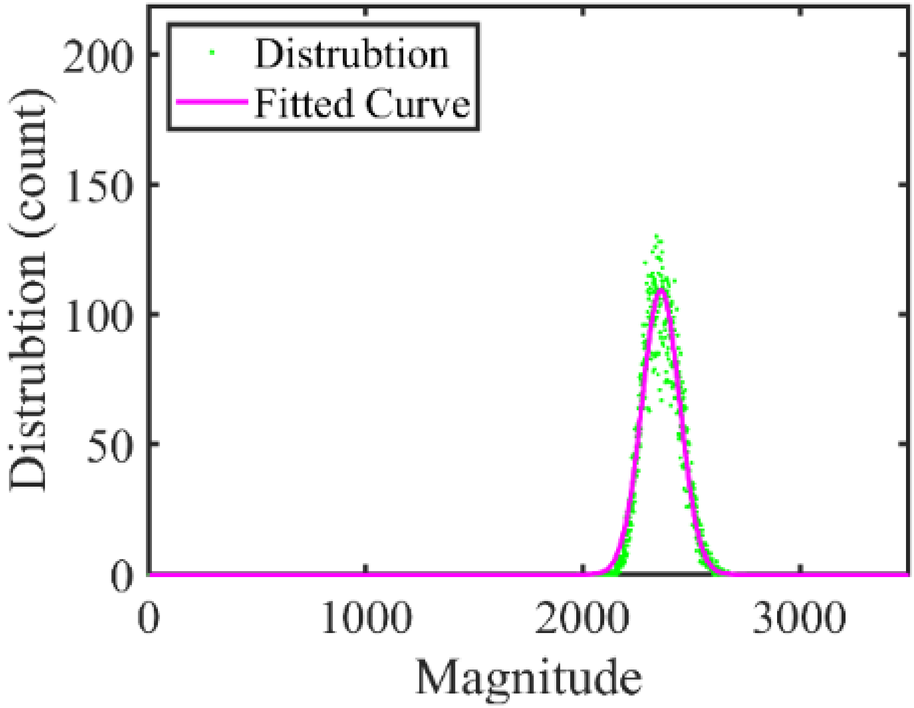
- Untreated samples results

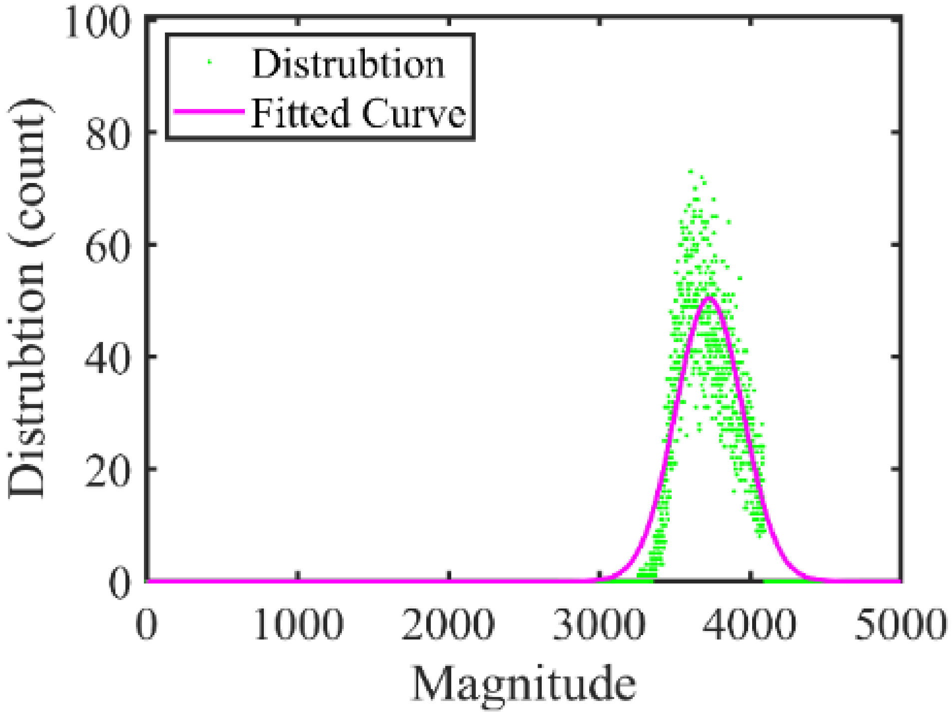




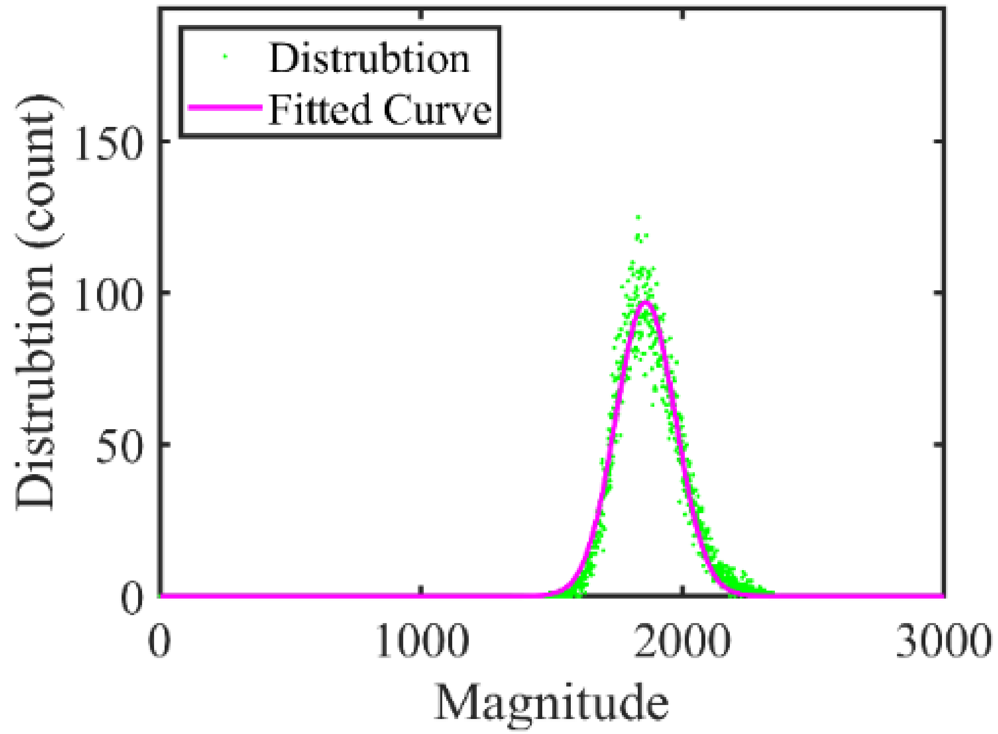
- MATLAB Examination Graphs

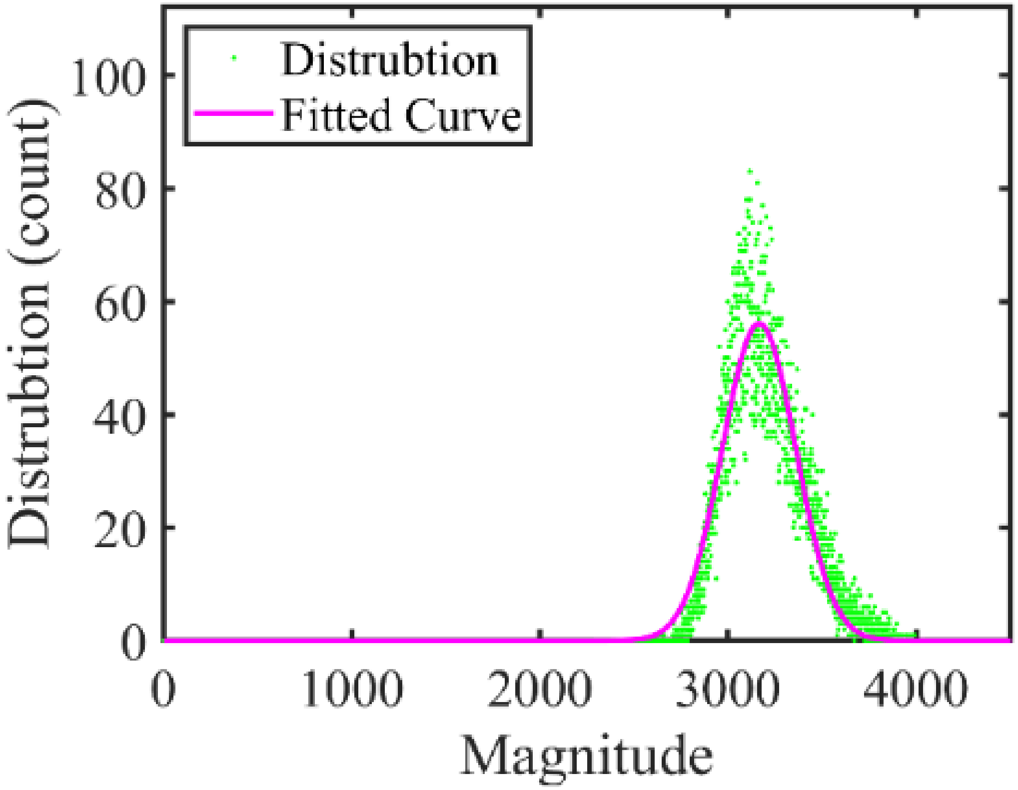
➢ Before and after annealing heat treatment process sample no 1.



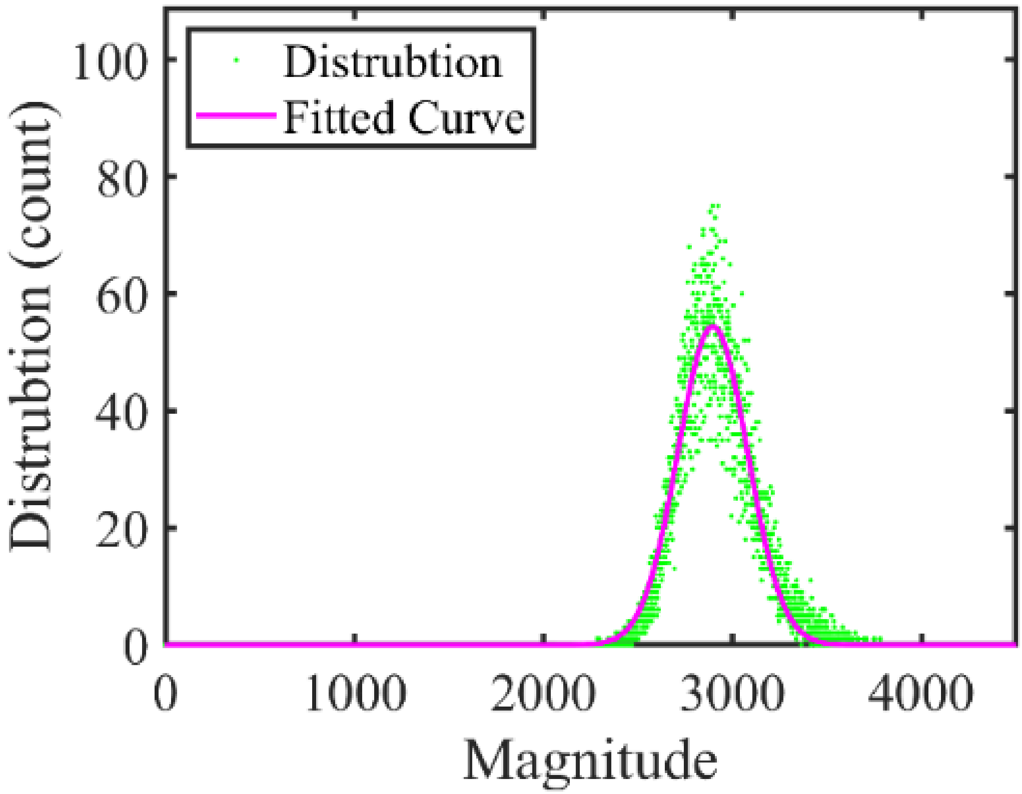


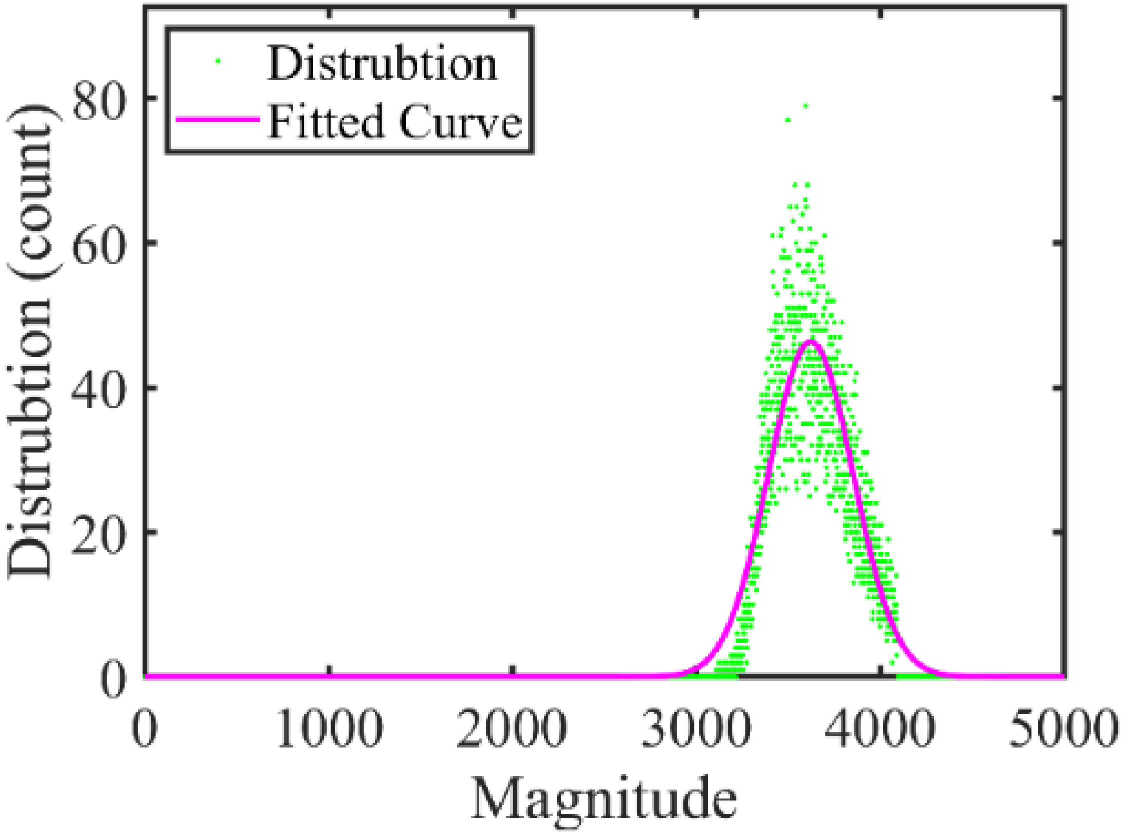
- *Before and after Normalising heat treatment process sample no 1*



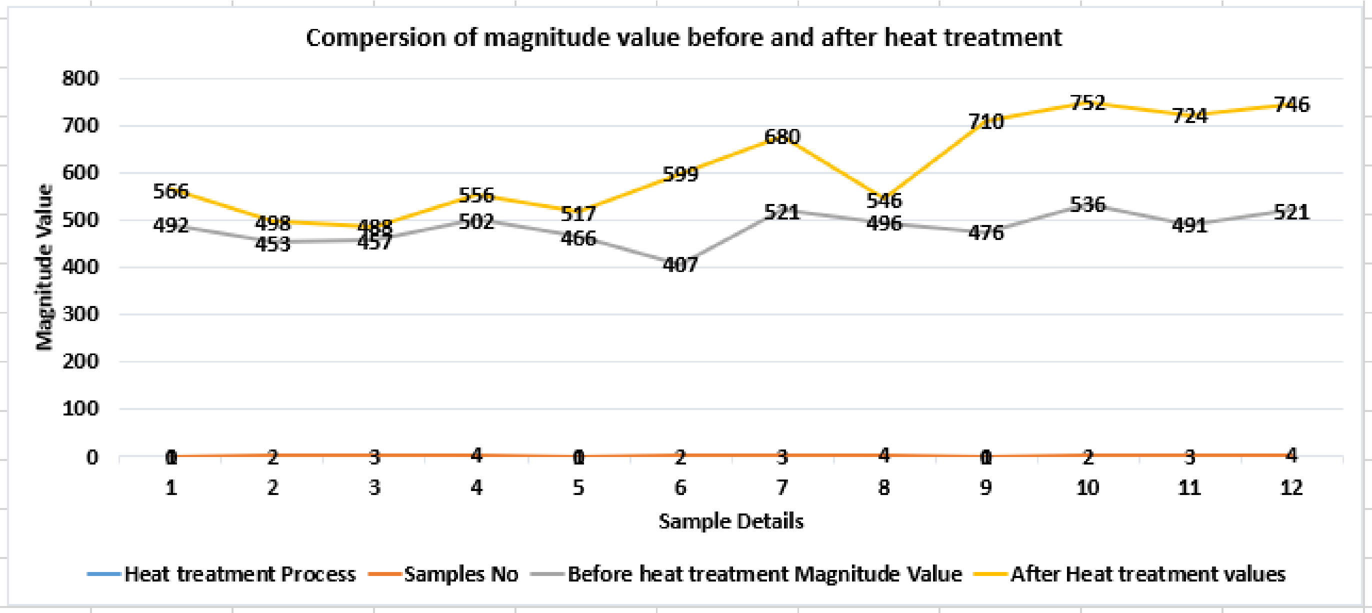


- Before and after quenching in water treated samples results

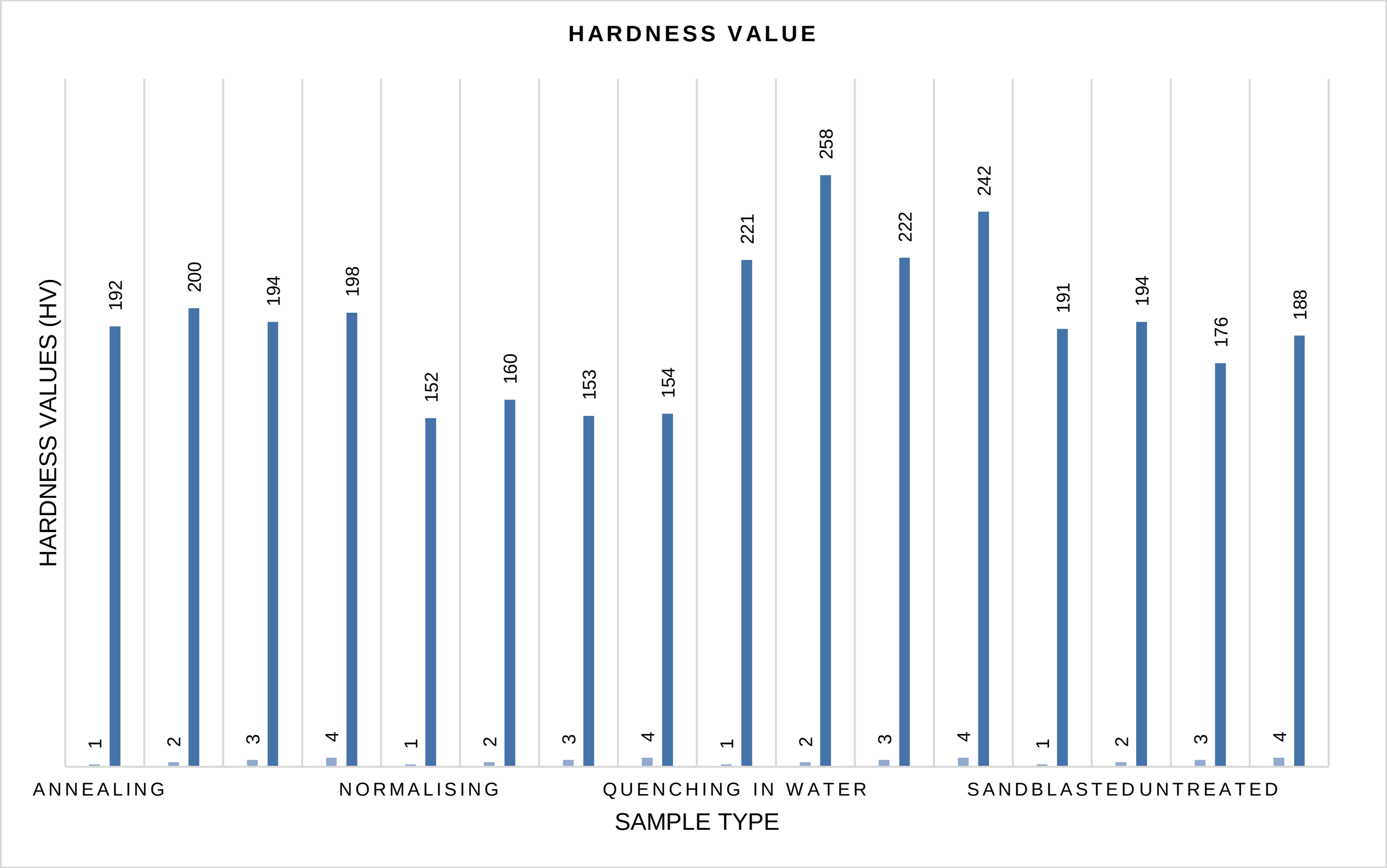




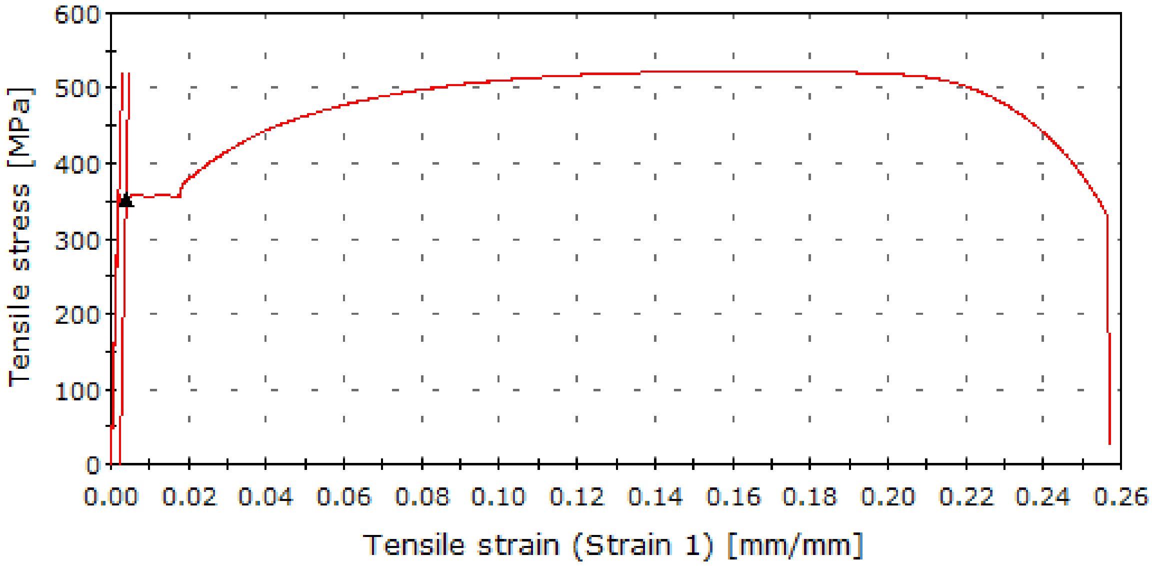
- ➢ Comparison of magnitude values before and after heat treatment process



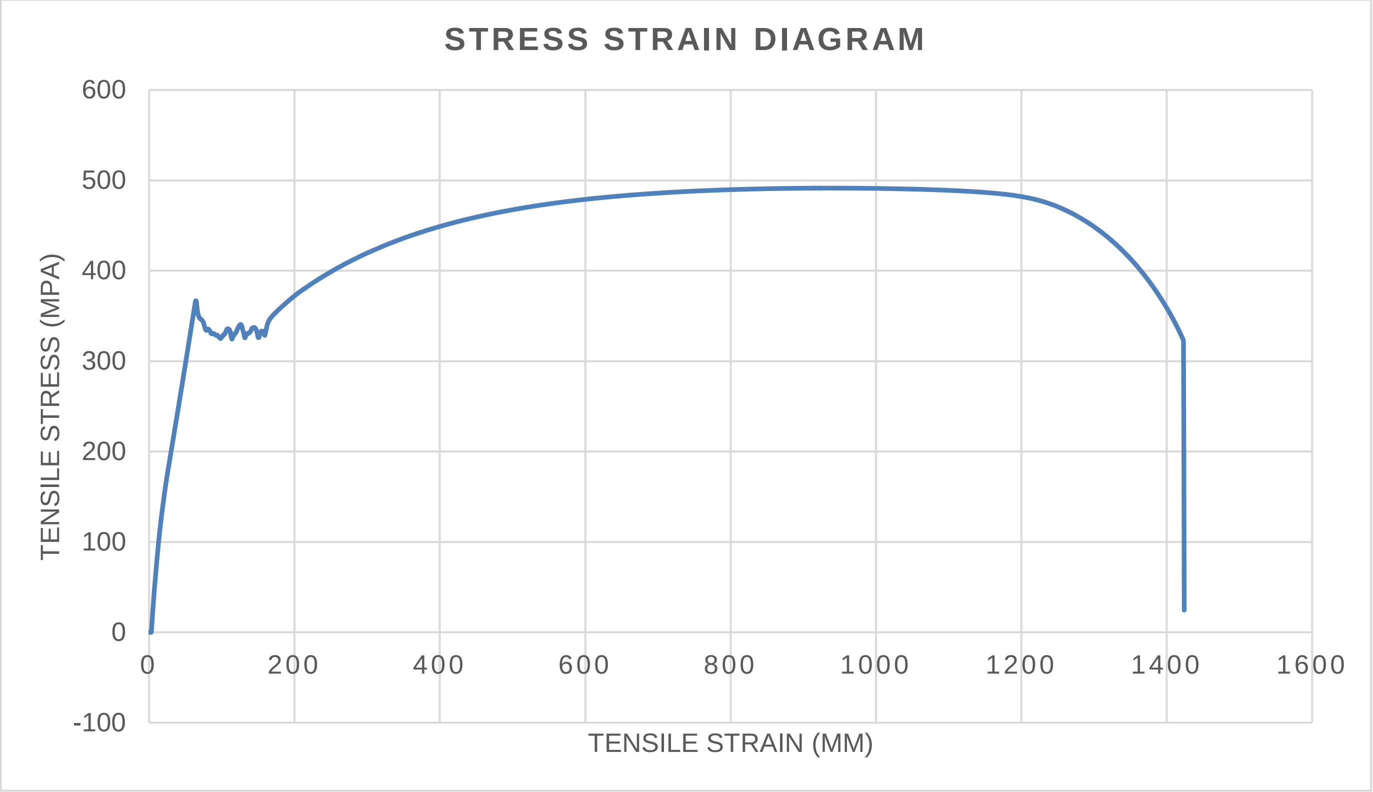
- ➢ Hardness values results of all samples



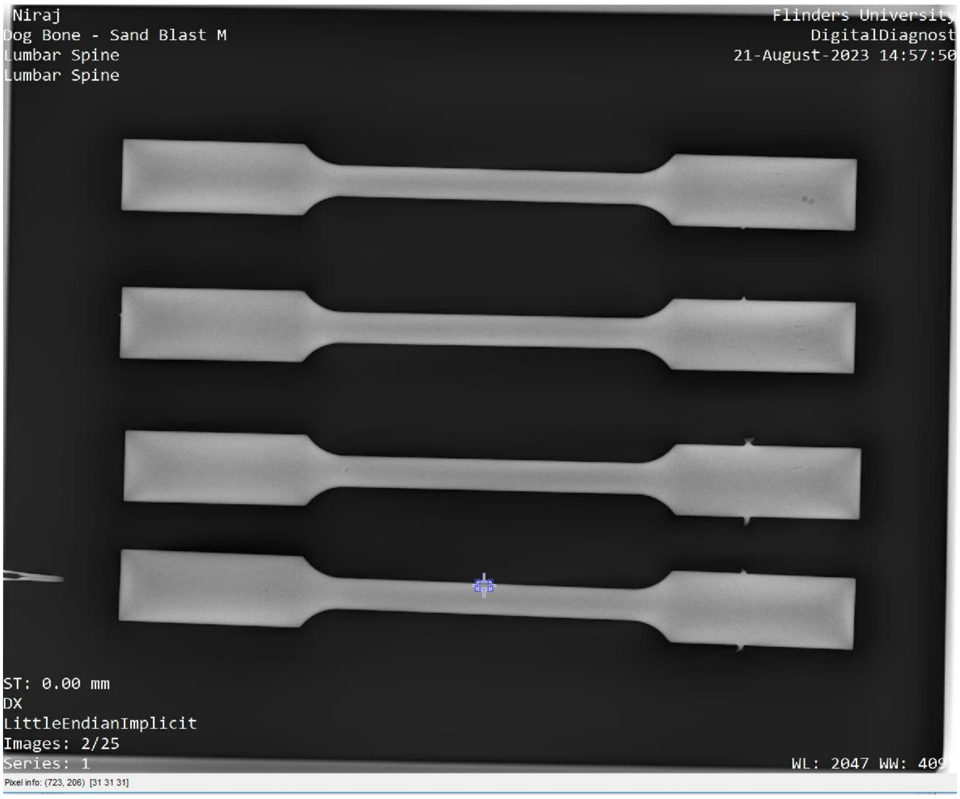
- Stress – Strain diagram from the machine



- Stress – Strain diagram from the excel data sheet.



- Pixels values from the MATLAB



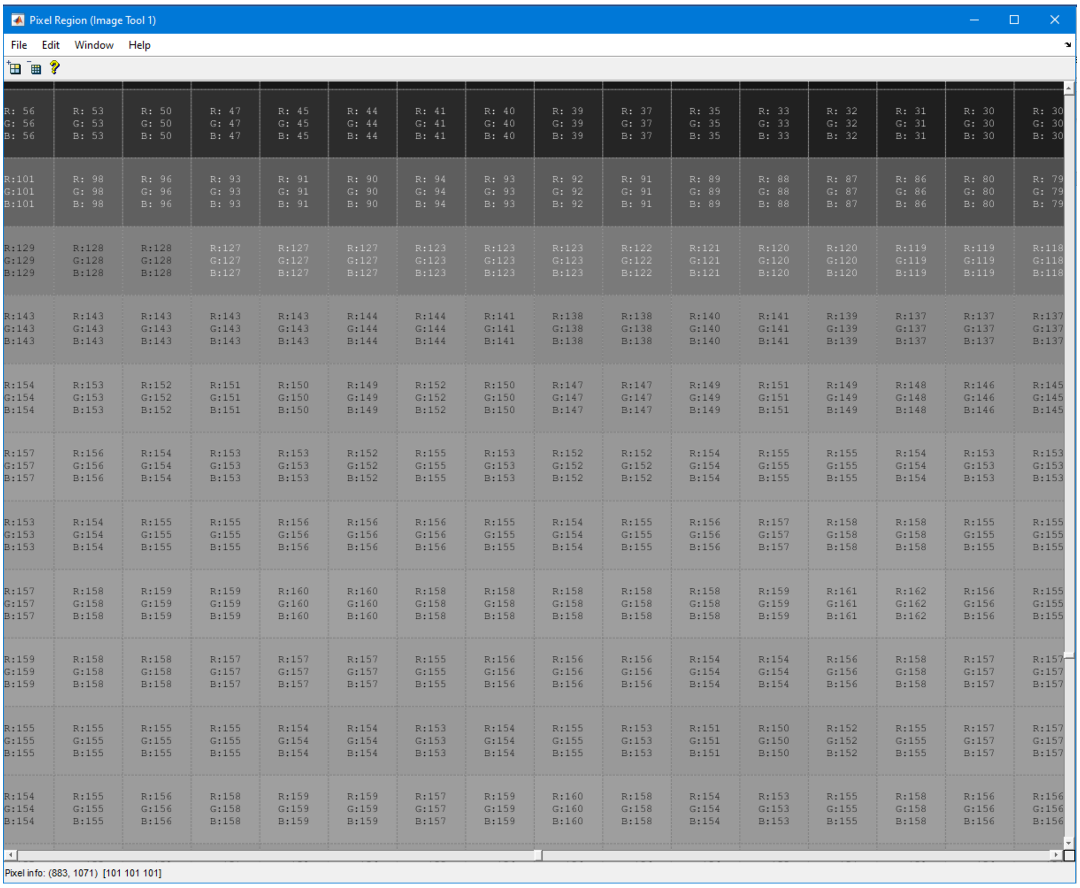
Niraj
Dog Bone - Sand Blast M
Lumbar Spine
Lumbar Spine

Flinders University
DigitalDiagnost
21-August-2023 14:57:50

ST: 0.00 mm
DX
LittleEndianImplicit
Images: 2/25
Series: 1

WL: 2047 WW: 409

Pixel info: (723, 206) [31 31 31]

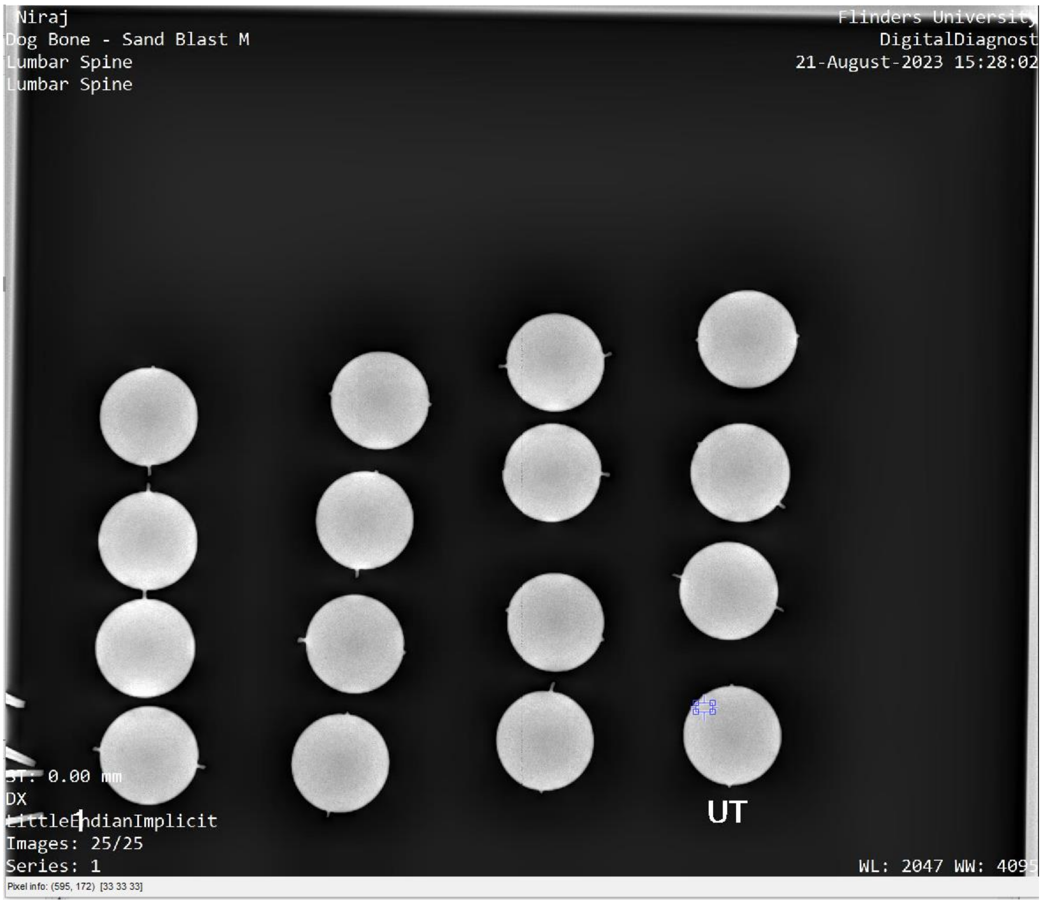


R: 56 G: 56 B: 56	R: 53 G: 53 B: 53	R: 50 G: 50 B: 50	R: 47 G: 47 B: 47	R: 45 G: 45 B: 45	R: 44 G: 44 B: 44	R: 41 G: 41 B: 41	R: 40 G: 40 B: 40	R: 39 G: 39 B: 39	R: 37 G: 37 B: 37	R: 35 G: 35 B: 35	R: 33 G: 33 B: 33	R: 32 G: 32 B: 32	R: 31 G: 31 B: 31	R: 30 G: 30 B: 30	R: 30 G: 30 B: 30
R:101 G:101 B:101	R: 98 G: 98 B: 98	R: 96 G: 96 B: 96	R: 93 G: 93 B: 93	R: 91 G: 91 B: 91	R: 90 G: 90 B: 90	R: 94 G: 94 B: 94	R: 93 G: 93 B: 93	R: 92 G: 92 B: 92	R: 91 G: 91 B: 91	R: 89 G: 89 B: 89	R: 88 G: 88 B: 88	R: 87 G: 87 B: 87	R: 86 G: 86 B: 86	R: 80 G: 80 B: 80	R: 79 G: 79 B: 79
R:129 G:129 B:129	R:128 G:128 B:128	R:128 G:128 B:128	R:127 G:127 B:127	R:127 G:127 B:127	R:127 G:127 B:127	R:123 G:123 B:123	R:123 G:123 B:123	R:123 G:123 B:123	R:122 G:122 B:122	R:121 G:121 B:121	R:120 G:120 B:120	R:120 G:120 B:120	R:119 G:119 B:119	R:119 G:119 B:119	R:118 G:118 B:118
R:143 G:143 B:143	R:143 G:143 B:143	R:143 G:143 B:143	R:143 G:143 B:143	R:143 G:143 B:143	R:144 G:144 B:144	R:144 G:144 B:144	R:141 G:141 B:141	R:138 G:138 B:138	R:138 G:138 B:138	R:140 G:140 B:140	R:141 G:141 B:141	R:139 G:139 B:139	R:137 G:137 B:137	R:137 G:137 B:137	R:137 G:137 B:137
R:154 G:154 B:154	R:153 G:153 B:153	R:152 G:152 B:152	R:151 G:151 B:151	R:150 G:150 B:150	R:149 G:149 B:149	R:152 G:152 B:152	R:150 G:150 B:150	R:147 G:147 B:147	R:147 G:147 B:147	R:149 G:149 B:149	R:151 G:151 B:151	R:149 G:149 B:149	R:148 G:148 B:148	R:146 G:146 B:146	R:145 G:145 B:145
R:157 G:157 B:157	R:156 G:156 B:156	R:154 G:154 B:154	R:153 G:153 B:153	R:153 G:153 B:153	R:152 G:152 B:152	R:155 G:155 B:155	R:153 G:153 B:153	R:152 G:152 B:152	R:152 G:152 B:152	R:154 G:154 B:154	R:155 G:155 B:155	R:155 G:155 B:155	R:154 G:154 B:154	R:153 G:153 B:153	R:153 G:153 B:153
R:153 G:153 B:153	R:154 G:154 B:154	R:155 G:155 B:155	R:155 G:155 B:155	R:156 G:156 B:156	R:156 G:156 B:156	R:156 G:156 B:156	R:155 G:155 B:155	R:154 G:154 B:154	R:155 G:155 B:155	R:156 G:156 B:156	R:157 G:157 B:157	R:158 G:158 B:158	R:158 G:158 B:158	R:155 G:155 B:155	R:155 G:155 B:155
R:157 G:157 B:157	R:158 G:158 B:158	R:159 G:159 B:159	R:159 G:159 B:159	R:160 G:160 B:160	R:160 G:160 B:160	R:158 G:158 B:158	R:158 G:158 B:158	R:158 G:158 B:158	R:158 G:158 B:158	R:158 G:158 B:158	R:159 G:159 B:159	R:161 G:161 B:161	R:162 G:162 B:162	R:156 G:156 B:156	R:155 G:155 B:155
R:159 G:159 B:159	R:158 G:158 B:158	R:158 G:158 B:158	R:157 G:157 B:157	R:157 G:157 B:157	R:157 G:157 B:157	R:155 G:155 B:155	R:156 G:156 B:156	R:156 G:156 B:156	R:156 G:156 B:156	R:154 G:154 B:154	R:154 G:154 B:154	R:156 G:156 B:156	R:158 G:158 B:158	R:157 G:157 B:157	R:157 G:157 B:157
R:155 G:155 B:155	R:155 G:155 B:155	R:155 G:155 B:155	R:155 G:155 B:155	R:154 G:154 B:154	R:154 G:154 B:154	R:153 G:153 B:153	R:154 G:154 B:154	R:155 G:155 B:155	R:153 G:153 B:153	R:151 G:151 B:151	R:150 G:150 B:150	R:152 G:152 B:152	R:155 G:155 B:155	R:157 G:157 B:157	R:157 G:157 B:157
R:154 G:154 B:154	R:155 G:155 B:155	R:156 G:156 B:156	R:158 G:158 B:158	R:159 G:159 B:159	R:159 G:159 B:159	R:157 G:157 B:157	R:159 G:159 B:159	R:160 G:160 B:160	R:158 G:158 B:158	R:154 G:154 B:154	R:153 G:153 B:153	R:155 G:155 B:155	R:158 G:158 B:158	R:156 G:156 B:156	R:156 G:156 B:156

Pixel info: (883, 1071) [101 101 101]

R:155 G:155 B:155	R:154 G:154 B:154	R:153 G:153 B:153	R:152 G:152 B:152	R:151 G:151 B:151	R:150 G:150 B:150	R:149 G:149 B:149	R:152 G:152 B:152	R:150 G:150 B:150	R:147 G:147 B:147	R:147 G:147 B:147	R:149 G:149 B:149	R:151 G:151 B:151	R:149 G:149 B:149	R:148 G:148 B:148	R:146 G:146 B:146
R:157 G:157 B:157	R:157 G:157 B:157	R:156 G:156 B:156	R:154 G:154 B:154	R:153 G:153 B:153	R:153 G:153 B:153	R:152 G:152 B:152	R:155 G:155 B:155	R:153 G:153 B:153	R:152 G:152 B:152	R:152 G:152 B:152	R:154 G:154 B:154	R:155 G:155 B:155	R:155 G:155 B:155	R:154 G:154 B:154	R:153 G:153 B:153
R:153 G:153 B:153	R:153 G:153 B:153	R:154 G:154 B:154	R:155 G:155 B:155	R:155 G:155 B:155	R:156 G:156 B:156	R:156 G:156 B:156	R:156 G:156 B:156	R:155 G:155 B:155	R:154 G:154 B:154	R:155 G:155 B:155	R:156 G:156 B:156	R:157 G:157 B:157	R:158 G:158 B:158	R:158 G:158 B:158	R:155 G:155 B:155
R:156 G:156 B:156	R:157 G:157 B:157	R:158 G:158 B:158	R:159 G:159 B:159	R:159 G:159 B:159	R:160 G:160 B:160	R:160 G:160 B:160	R:158 G:158 B:158	R:158 G:158 B:158	R:158 G:158 B:158	R:158 G:158 B:158	R:158 G:158 B:158	R:159 G:159 B:159	R:161 G:161 B:161	R:162 G:162 B:162	R:156 G:156 B:156
R:159 G:159 B:159	R:159 G:159 B:159	R:158 G:158 B:158	R:158 G:158 B:158	R:157 G:157 B:157	R:157 G:157 B:157	R:157 G:157 B:157	R:155 G:155 B:155	R:156 G:156 B:156	R:156 G:156 B:156	R:156 G:156 B:156	R:154 G:154 B:154	R:154 G:154 B:154	R:156 G:156 B:156	R:158 G:158 B:158	R:157 G:157 B:157
R:155 G:155 B:155	R:155 G:155 B:155	R:155 G:155 B:155	R:155 G:155 B:155	R:155 G:155 B:155	R:154 G:154 B:154	R:154 G:154 B:154	R:153 G:153 B:153	R:154 G:154 B:154	R:155 G:155 B:155	R:153 G:153 B:153	R:151 G:151 B:151	R:150 G:150 B:150	R:152 G:152 B:152	R:155 G:155 B:155	R:157 G:157 B:157
R:153 G:153 B:153	R:154 G:154 B:154	R:155 G:155 B:155	R:156 G:156 B:156	R:158 G:158 B:158	R:159 G:159 B:159	R:159 G:159 B:159	R:157 G:157 B:157	R:159 G:159 B:159	R:160 G:160 B:160	R:158 G:158 B:158	R:154 G:154 B:154	R:153 G:153 B:153	R:155 G:155 B:155	R:158 G:158 B:158	R:156 G:156 B:156
R:156 G:156 B:156	R:157 G:157 B:157	R:155 G:155 B:155	R:152 G:152 B:152	R:151 G:151 B:151	R:153 G:153 B:153	R:156 G:156 B:156	R:155 G:155 B:155	R:156 G:156 B:156	R:156 G:156 B:156	R:156 G:156 B:156	R:156 G:156 B:156	R:155 G:155 B:155	R:154 G:154 B:154	R:153 G:153 B:153	R:156 G:156 B:156
R:157 G:157 B:157	R:157 G:157 B:157	R:156 G:156 B:156	R:153 G:153 B:153	R:152 G:152 B:152	R:153 G:153 B:153	R:156 G:156 B:156	R:155 G:155 B:155	R:155 G:155 B:155	R:156 G:156 B:156	R:156 G:156 B:156	R:155 G:155 B:155	R:154 G:154 B:154	R:153 G:153 B:153	R:153 G:153 B:153	R:155 G:155 B:155
R:158 G:158 B:158	R:157 G:157 B:157	R:155 G:155 B:155	R:153 G:153 B:153	R:152 G:152 B:152	R:153 G:153 B:153	R:154 G:154 B:154	R:154 G:154 B:154	R:154 G:154 B:154	R:155 G:155 B:155	R:155 G:155 B:155	R:154 G:154 B:154	R:154 G:154 B:154	R:153 G:153 B:153	R:152 G:152 B:152	R:154 G:154 B:154
R:156 G:156 B:156	R:155 G:155 B:155	R:153 G:153 B:153	R:152 G:152 B:152	R:151 G:151 B:151	R:151 G:151 B:151	R:152 G:152 B:152	R:153 G:153 B:153	R:153 G:153 B:153	R:154 G:154 B:154	R:154 G:154 B:154	R:153 G:153 B:153	R:152 G:152 B:152	R:151 G:151 B:151	R:151 G:151 B:151	R:152 G:152 B:152
R:153	R:151	R:150	R:150	R:150	R:149	R:149	R:152	R:152	R:152	R:152	R:152	R:151	R:150	R:150	R:150

Pixel info: (X, Y) [R G B]



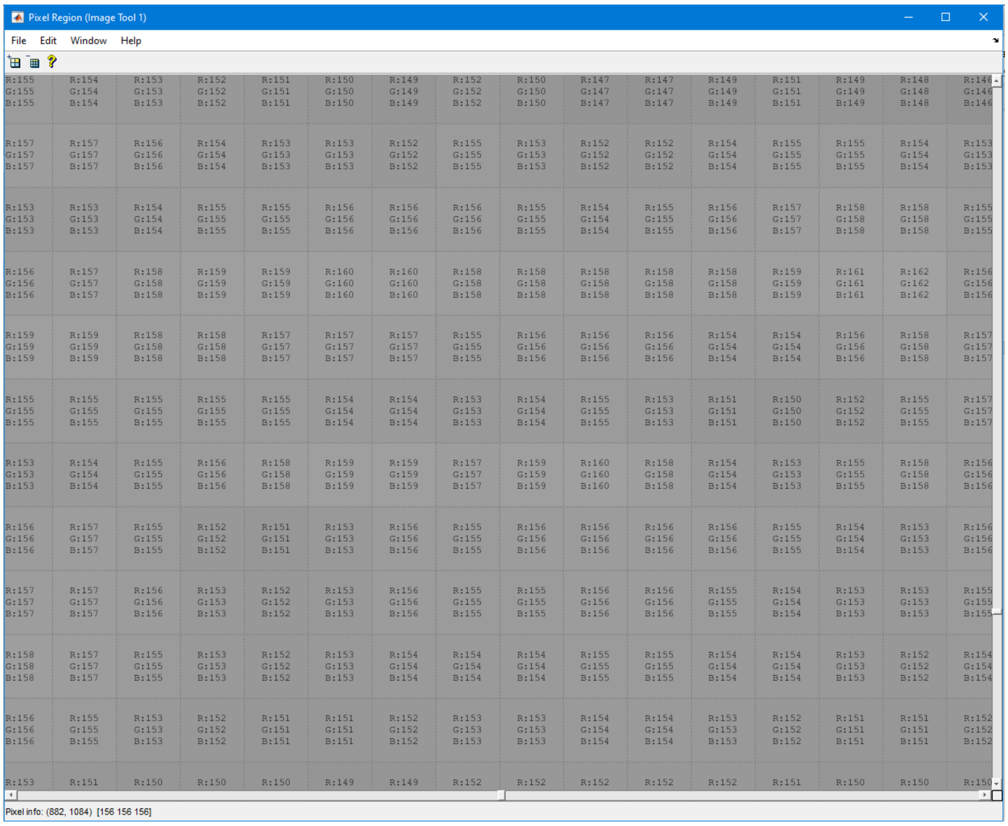
Niraj
Dog Bone - Sand Blast M
Lumbar Spine
Lumbar Spine

Flinders University
DigitalDiagnost
21-August-2023 15:28:02

ST: 0.00 mm
DX
LittleEndianImplicit
Images: 25/25
Series: 1

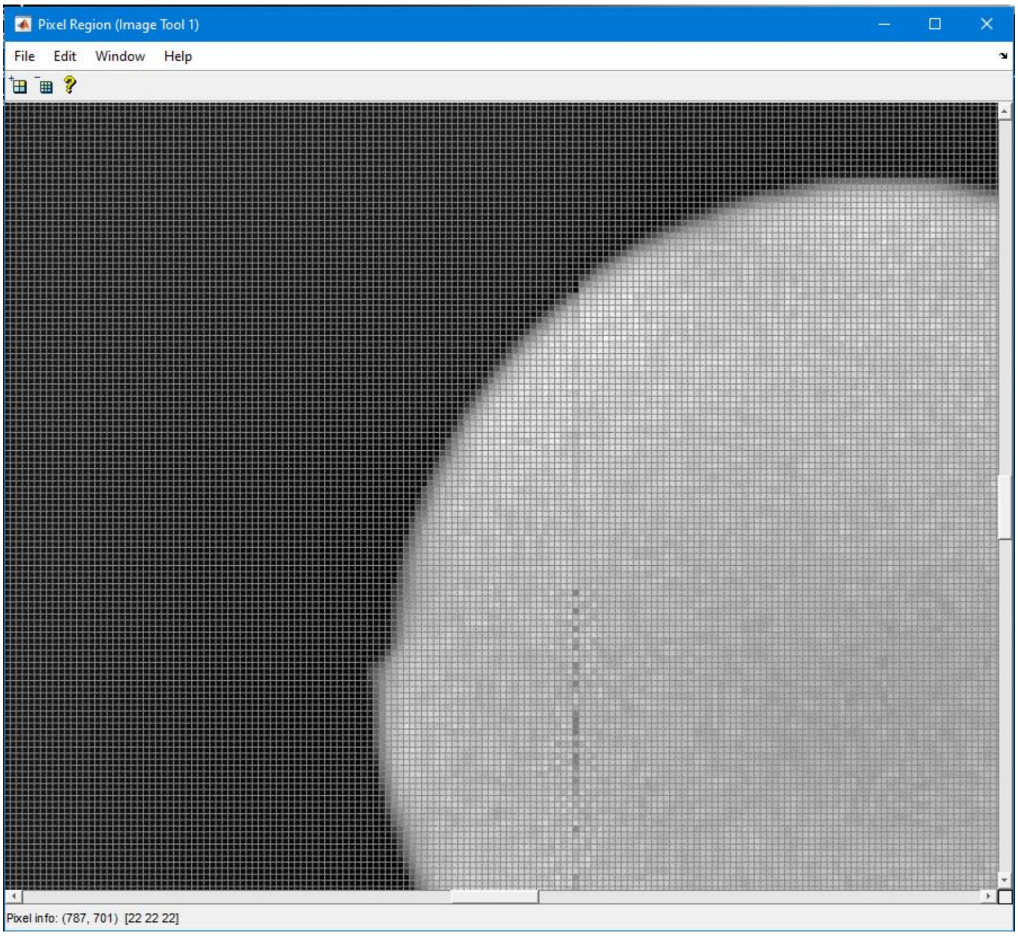
WL: 2047 WW: 4095

Pixel info: (595, 172) [33 33 33]

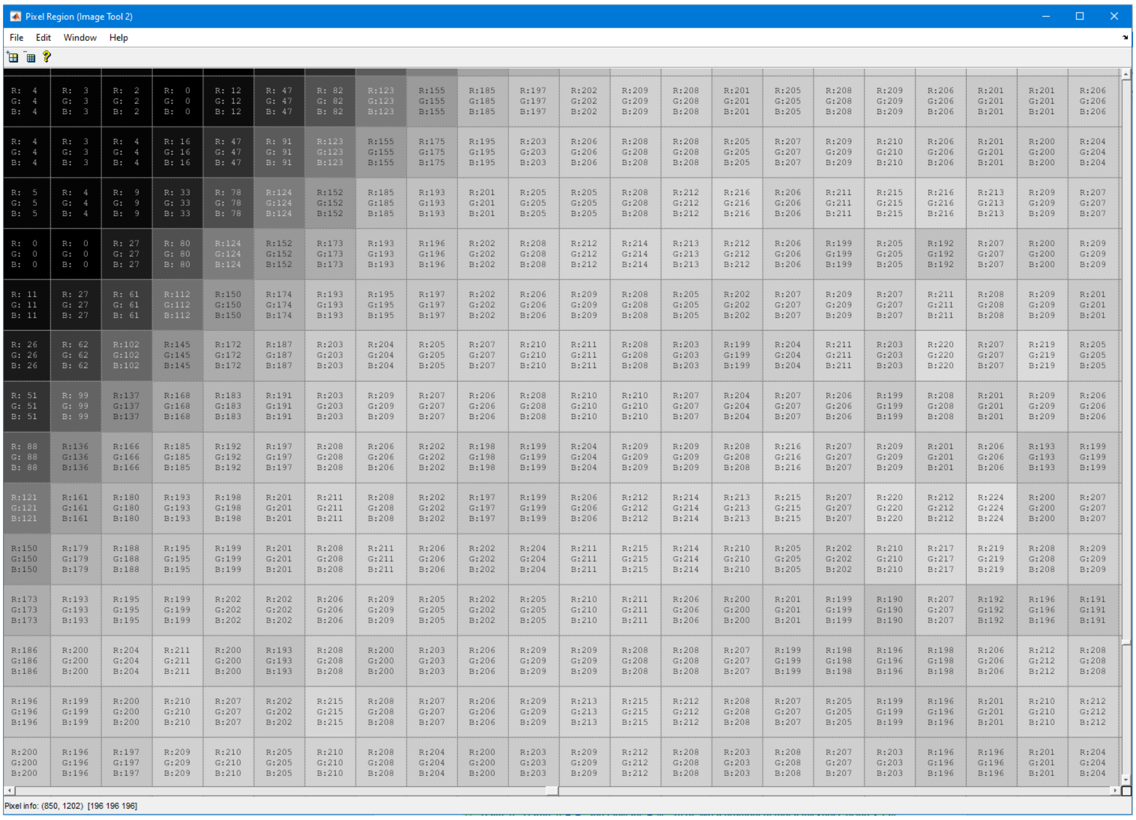


R:155 G:155 B:155	R:154 G:154 B:154	R:153 G:153 B:153	R:152 G:152 B:152	R:151 G:151 B:151	R:150 G:150 B:150	R:149 G:149 B:149	R:152 G:152 B:152	R:150 G:150 B:150	R:147 G:147 B:147	R:147 G:147 B:147	R:149 G:149 B:149	R:151 G:151 B:151	R:149 G:149 B:149	R:148 G:148 B:148	R:146 G:146 B:146
R:157 G:157 B:157	R:157 G:157 B:157	R:156 G:156 B:156	R:154 G:154 B:154	R:153 G:153 B:153	R:153 G:153 B:153	R:152 G:152 B:152	R:155 G:155 B:155	R:153 G:153 B:153	R:152 G:152 B:152	R:152 G:152 B:152	R:154 G:154 B:154	R:155 G:155 B:155	R:155 G:155 B:155	R:154 G:154 B:154	R:153 G:153 B:153
R:153 G:153 B:153	R:153 G:153 B:153	R:154 G:154 B:154	R:155 G:155 B:155	R:155 G:155 B:155	R:156 G:156 B:156	R:156 G:156 B:156	R:156 G:156 B:156	R:155 G:155 B:155	R:154 G:154 B:154	R:155 G:155 B:155	R:156 G:156 B:156	R:157 G:157 B:157	R:158 G:158 B:158	R:158 G:158 B:158	R:155 G:155 B:155
R:156 G:156 B:156	R:157 G:157 B:157	R:158 G:158 B:158	R:159 G:159 B:159	R:159 G:159 B:159	R:160 G:160 B:160	R:160 G:160 B:160	R:158 G:158 B:158	R:158 G:158 B:158	R:158 G:158 B:158	R:158 G:158 B:158	R:158 G:158 B:158	R:159 G:159 B:159	R:161 G:161 B:161	R:162 G:162 B:162	R:156 G:156 B:156
R:159 G:159 B:159	R:159 G:159 B:159	R:158 G:158 B:158	R:158 G:158 B:158	R:157 G:157 B:157	R:157 G:157 B:157	R:157 G:157 B:157	R:155 G:155 B:155	R:156 G:156 B:156	R:156 G:156 B:156	R:156 G:156 B:156	R:154 G:154 B:154	R:154 G:154 B:154	R:156 G:156 B:156	R:158 G:158 B:158	R:157 G:157 B:157
R:155 G:155 B:155	R:155 G:155 B:155	R:155 G:155 B:155	R:155 G:155 B:155	R:155 G:155 B:155	R:154 G:154 B:154	R:154 G:154 B:154	R:153 G:153 B:153	R:154 G:154 B:154	R:155 G:155 B:155	R:153 G:153 B:153	R:151 G:151 B:151	R:150 G:150 B:150	R:152 G:152 B:152	R:155 G:155 B:155	R:157 G:157 B:157
R:153 G:153 B:153	R:154 G:154 B:154	R:155 G:155 B:155	R:156 G:156 B:156	R:158 G:158 B:158	R:159 G:159 B:159	R:159 G:159 B:159	R:157 G:157 B:157	R:159 G:159 B:159	R:160 G:160 B:160	R:158 G:158 B:158	R:154 G:154 B:154	R:153 G:153 B:153	R:155 G:155 B:155	R:158 G:158 B:158	R:156 G:156 B:156
R:156 G:156 B:156	R:157 G:157 B:157	R:155 G:155 B:155	R:152 G:152 B:152	R:151 G:151 B:151	R:153 G:153 B:153	R:156 G:156 B:156	R:155 G:155 B:155	R:156 G:156 B:156	R:156 G:156 B:156	R:156 G:156 B:156	R:156 G:156 B:156	R:155 G:155 B:155	R:154 G:154 B:154	R:153 G:153 B:153	R:156 G:156 B:156
R:157 G:157 B:157	R:157 G:157 B:157	R:156 G:156 B:156	R:153 G:153 B:153	R:152 G:152 B:152	R:153 G:153 B:153	R:156 G:156 B:156	R:155 G:155 B:155	R:155 G:155 B:155	R:156 G:156 B:156	R:156 G:156 B:156	R:155 G:155 B:155	R:154 G:154 B:154	R:153 G:153 B:153	R:153 G:153 B:153	R:155 G:155 B:155
R:158 G:158 B:158	R:157 G:157 B:157	R:155 G:155 B:155	R:153 G:153 B:153	R:152 G:152 B:152	R:153 G:153 B:153	R:154 G:154 B:154	R:154 G:154 B:154	R:154 G:154 B:154	R:155 G:155 B:155	R:155 G:155 B:155	R:154 G:154 B:154	R:154 G:154 B:154	R:153 G:153 B:153	R:152 G:152 B:152	R:154 G:154 B:154
R:156 G:156 B:156	R:155 G:155 B:155	R:153 G:153 B:153	R:152 G:152 B:152	R:151 G:151 B:151	R:151 G:151 B:151	R:152 G:152 B:152	R:153 G:153 B:153	R:153 G:153 B:153	R:154 G:154 B:154	R:154 G:154 B:154	R:153 G:153 B:153	R:152 G:152 B:152	R:151 G:151 B:151	R:151 G:151 B:151	R:152 G:152 B:152
R:153	R:151	R:150	R:150	R:150	R:149	R:149	R:152	R:152	R:152	R:152	R:152	R:151	R:150	R:150	R:150

Pixel info: (882, 1084) [156 156 156]



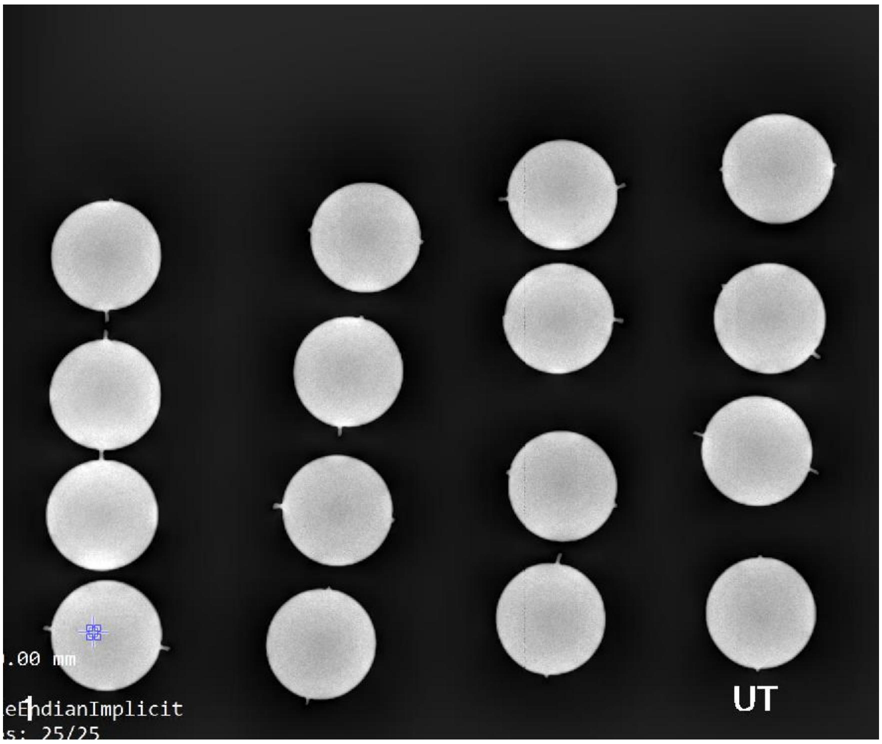
Pixel info: (787, 701) [22 22 22]

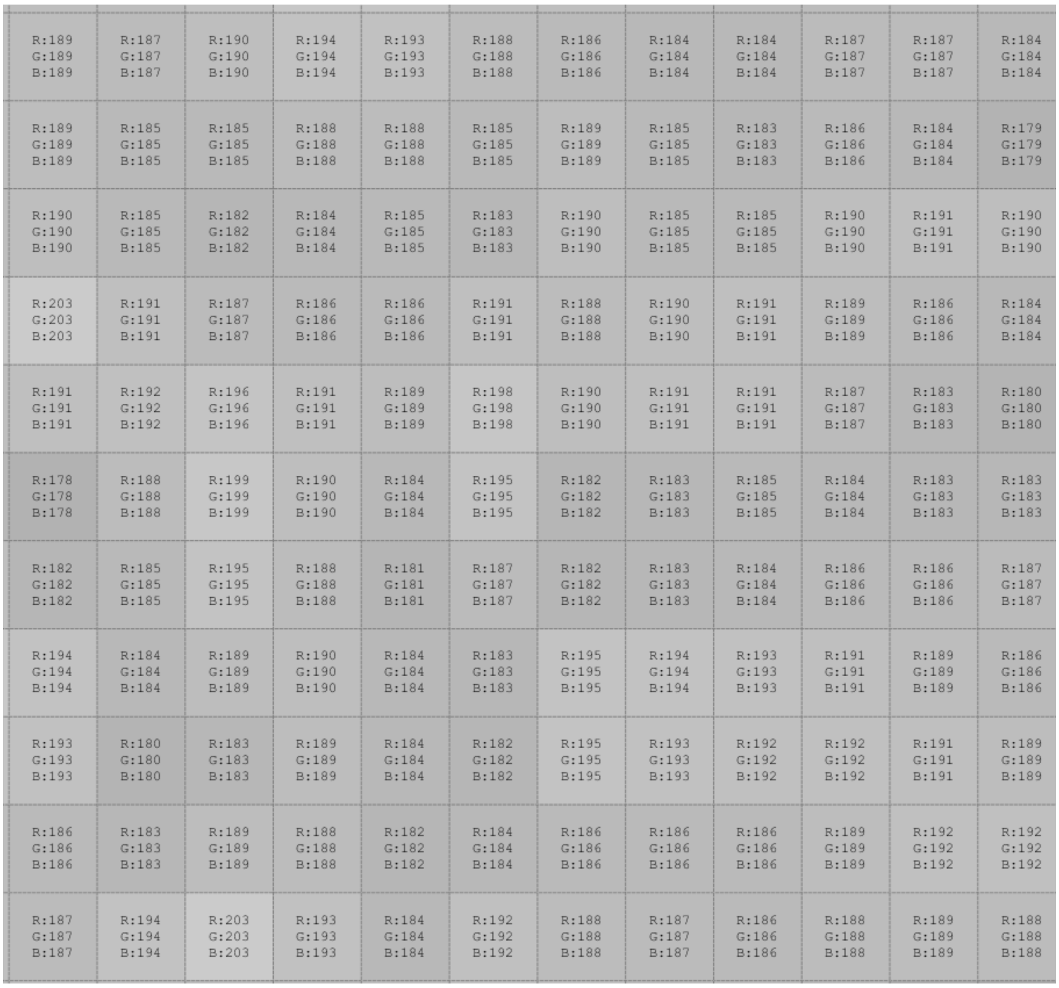


R: 4 G: 4 B: 4	R: 3 G: 3 B: 3	R: 2 G: 2 B: 2	R: 0 G: 0 B: 0	R: 12 G: 12 B: 12	R: 47 G: 47 B: 47	R: 82 G: 82 B: 82	R:123 G:123 B:123	R:155 G:155 B:155	R:185 G:185 B:185	R:197 G:197 B:197	R:202 G:202 B:202	R:209 G:209 B:209	R:208 G:208 B:208	R:201 G:201 B:201	R:205 G:205 B:205	R:208 G:208 B:208	R:209 G:209 B:209	R:206 G:206 B:206	R:201 G:201 B:201	R:201 G:201 B:201	R:206 G:206 B:206
R: 4 G: 4 B: 4	R: 3 G: 3 B: 3	R: 4 G: 4 B: 4	R: 16 G: 16 B: 16	R: 47 G: 47 B: 47	R: 91 G: 91 B: 91	R:123 G:123 B:123	R:155 G:155 B:155	R:175 G:175 B:175	R:195 G:195 B:195	R:203 G:203 B:203	R:206 G:206 B:206	R:208 G:208 B:208	R:208 G:208 B:208	R:205 G:205 B:205	R:207 G:207 B:207	R:209 G:209 B:209	R:210 G:210 B:210	R:206 G:206 B:206	R:201 G:201 B:201	R:200 G:200 B:200	R:204 G:204 B:204
R: 5 G: 5 B: 5	R: 4 G: 4 B: 4	R: 9 G: 9 B: 9	R: 33 G: 33 B: 33	R: 78 G: 78 B: 78	R:124 G:124 B:124	R:152 G:152 B:152	R:185 G:185 B:185	R:193 G:193 B:193	R:201 G:201 B:201	R:205 G:205 B:205	R:205 G:205 B:205	R:208 G:208 B:208	R:212 G:212 B:212	R:216 G:216 B:216	R:206 G:206 B:206	R:211 G:211 B:211	R:215 G:215 B:215	R:216 G:216 B:216	R:213 G:213 B:213	R:209 G:209 B:209	R:207 G:207 B:207
R: 0 G: 0 B: 0	R: 0 G: 0 B: 0	R: 27 G: 27 B: 27	R: 80 G: 80 B: 80	R:124 G:124 B:124	R:152 G:152 B:152	R:173 G:173 B:173	R:193 G:193 B:193	R:196 G:196 B:196	R:202 G:202 B:202	R:208 G:208 B:208	R:212 G:212 B:212	R:214 G:214 B:214	R:213 G:213 B:213	R:212 G:212 B:212	R:206 G:206 B:206	R:199 G:199 B:199	R:205 G:205 B:205	R:192 G:192 B:192	R:207 G:207 B:207	R:200 G:200 B:200	R:209 G:209 B:209
R: 11 G: 11 B: 11	R: 27 G: 27 B: 27	R: 61 G: 61 B: 61	R:112 G:112 B:112	R:150 G:150 B:150	R:174 G:174 B:174	R:193 G:193 B:193	R:195 G:195 B:195	R:197 G:197 B:197	R:202 G:202 B:202	R:206 G:206 B:206	R:209 G:209 B:209	R:208 G:208 B:208	R:205 G:205 B:205	R:202 G:202 B:202	R:207 G:207 B:207	R:209 G:209 B:209	R:207 G:207 B:207	R:211 G:211 B:211	R:208 G:208 B:208	R:209 G:209 B:209	R:201 G:201 B:201
R: 26 G: 26 B: 26	R: 62 G: 62 B: 62	R:102 G:102 B:102	R:145 G:145 B:145	R:172 G:172 B:172	R:187 G:187 B:187	R:203 G:203 B:203	R:204 G:204 B:204	R:205 G:205 B:205	R:207 G:207 B:207	R:210 G:210 B:210	R:211 G:211 B:211	R:208 G:208 B:208	R:203 G:203 B:203	R:199 G:199 B:199	R:204 G:204 B:204	R:211 G:211 B:211	R:203 G:203 B:203	R:220 G:220 B:220	R:207 G:207 B:207	R:219 G:219 B:219	R:205 G:205 B:205
R: 51 G: 51 B: 51	R: 99 G: 99 B: 99	R:137 G:137 B:137	R:168 G:168 B:168	R:183 G:183 B:183	R:191 G:191 B:191	R:203 G:203 B:203	R:209 G:209 B:209	R:207 G:207 B:207	R:206 G:206 B:206	R:208 G:208 B:208	R:210 G:210 B:210	R:210 G:210 B:210	R:207 G:207 B:207	R:204 G:204 B:204	R:207 G:207 B:207	R:206 G:206 B:206	R:199 G:199 B:199	R:208 G:208 B:208	R:201 G:201 B:201	R:209 G:209 B:209	R:206 G:206 B:206
R: 88 G: 88 B: 88	R:136 G:136 B:136	R:166 G:166 B:166	R:185 G:185 B:185	R:192 G:192 B:192	R:197 G:197 B:197	R:208 G:208 B:208	R:206 G:206 B:206	R:202 G:202 B:202	R:198 G:198 B:198	R:199 G:199 B:199	R:204 G:204 B:204	R:209 G:209 B:209	R:209 G:209 B:209	R:208 G:208 B:208	R:216 G:216 B:216	R:207 G:207 B:207	R:209 G:209 B:209	R:201 G:201 B:201	R:206 G:206 B:206	R:193 G:193 B:193	R:199 G:199 B:199
R:121 G:121 B:121	R:161 G:161 B:161	R:180 G:180 B:180	R:193 G:193 B:193	R:198 G:198 B:198	R:201 G:201 B:201	R:211 G:211 B:211	R:208 G:208 B:208	R:202 G:202 B:202	R:197 G:197 B:197	R:199 G:199 B:199	R:206 G:206 B:206	R:212 G:212 B:212	R:214 G:214 B:214	R:213 G:213 B:213	R:215 G:215 B:215	R:207 G:207 B:207	R:220 G:220 B:220	R:212 G:212 B:212	R:224 G:224 B:224	R:200 G:200 B:200	R:207 G:207 B:207
R:150 G:150 B:150	R:179 G:179 B:179	R:188 G:188 B:188	R:195 G:195 B:195	R:199 G:199 B:199	R:201 G:201 B:201	R:208 G:208 B:208	R:211 G:211 B:211	R:206 G:206 B:206	R:202 G:202 B:202	R:204 G:204 B:204	R:211 G:211 B:211	R:215 G:215 B:215	R:214 G:214 B:214	R:210 G:210 B:210	R:205 G:205 B:205	R:202 G:202 B:202	R:210 G:210 B:210	R:217 G:217 B:217	R:219 G:219 B:219	R:208 G:208 B:208	R:209 G:209 B:209
R:173 G:173 B:173	R:193 G:193 B:193	R:195 G:195 B:195	R:199 G:199 B:199	R:202 G:202 B:202	R:202 G:202 B:202	R:206 G:206 B:206	R:209 G:209 B:209	R:205 G:205 B:205	R:202 G:202 B:202	R:205 G:205 B:205	R:210 G:210 B:210	R:211 G:211 B:211	R:206 G:206 B:206	R:200 G:200 B:200	R:201 G:201 B:201	R:199 G:199 B:199	R:190 G:190 B:190	R:207 G:207 B:207	R:192 G:192 B:192	R:196 G:196 B:196	R:191 G:191 B:191
R:186 G:186 B:186	R:200 G:200 B:200	R:204 G:204 B:204	R:211 G:211 B:211	R:200 G:200 B:200	R:193 G:193 B:193	R:208 G:208 B:208	R:200 G:200 B:200	R:203 G:203 B:203	R:206 G:206 B:206	R:209 G:209 B:209	R:209 G:209 B:209	R:208 G:208 B:208	R:208 G:208 B:208	R:207 G:207 B:207	R:199 G:199 B:199	R:198 G:198 B:198	R:196 G:196 B:196	R:198 G:198 B:198	R:206 G:206 B:206	R:212 G:212 B:212	R:208 G:208 B:208
R:196 G:196 B:196	R:199 G:199 B:199	R:200 G:200 B:200	R:210 G:210 B:210	R:207 G:207 B:207	R:202 G:202 B:202	R:215 G:215 B:215	R:208 G:208 B:208	R:207 G:207 B:207	R:206 G:206 B:206	R:209 G:209 B:209	R:213 G:213 B:213	R:215 G:215 B:215	R:212 G:212 B:212	R:208 G:208 B:208	R:207 G:207 B:207	R:205 G:205 B:205	R:199 G:199 B:199	R:196 G:196 B:196	R:201 G:201 B:201	R:210 G:210 B:210	R:212 G:212 B:212
R:200 G:200 B:200	R:196 G:196 B:196	R:197 G:197 B:197	R:209 G:209 B:209	R:210 G:210 B:210	R:205 G:205 B:205	R:210 G:210 B:210	R:208 G:208 B:208	R:204 G:204 B:204	R:200 G:200 B:200	R:203 G:203 B:203	R:209 G:209 B:209	R:212 G:212 B:212	R:208 G:208 B:208	R:203 G:203 B:203	R:208 G:208 B:208	R:207 G:207 B:207	R:203 G:203 B:203	R:196 G:196 B:196	R:196 G:196 B:196	R:201 G:201 B:201	R:204 G:204 B:204

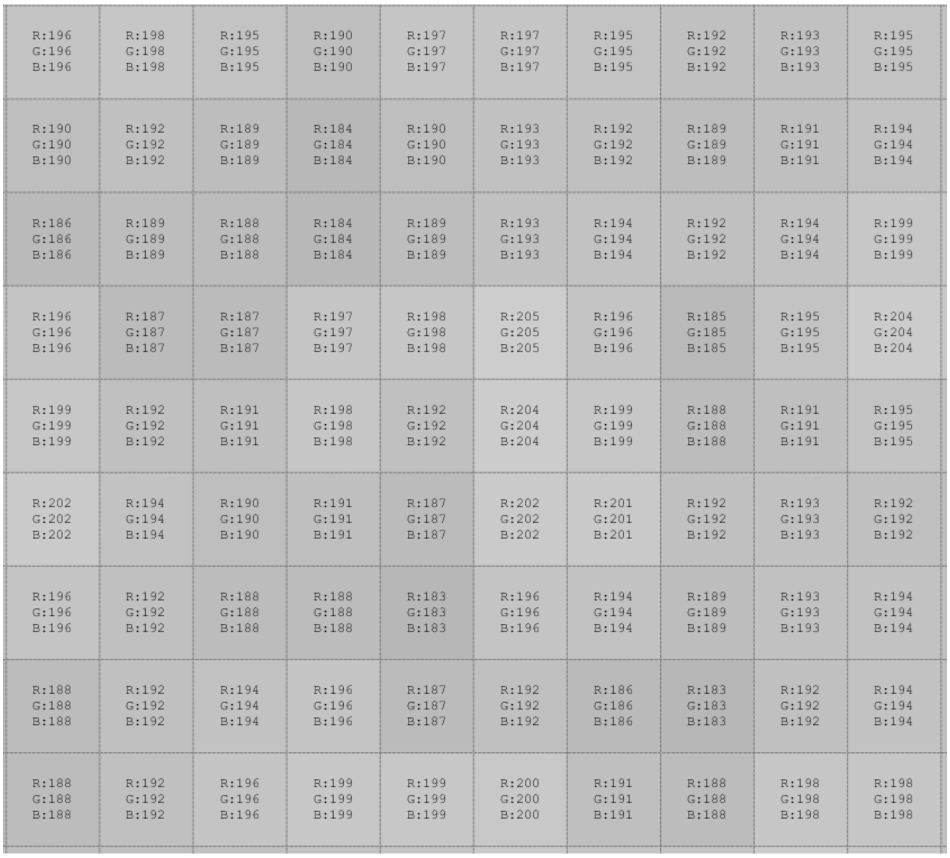
Pixel info: (850, 1202) [196 196 196]

- Hardness results pixels values



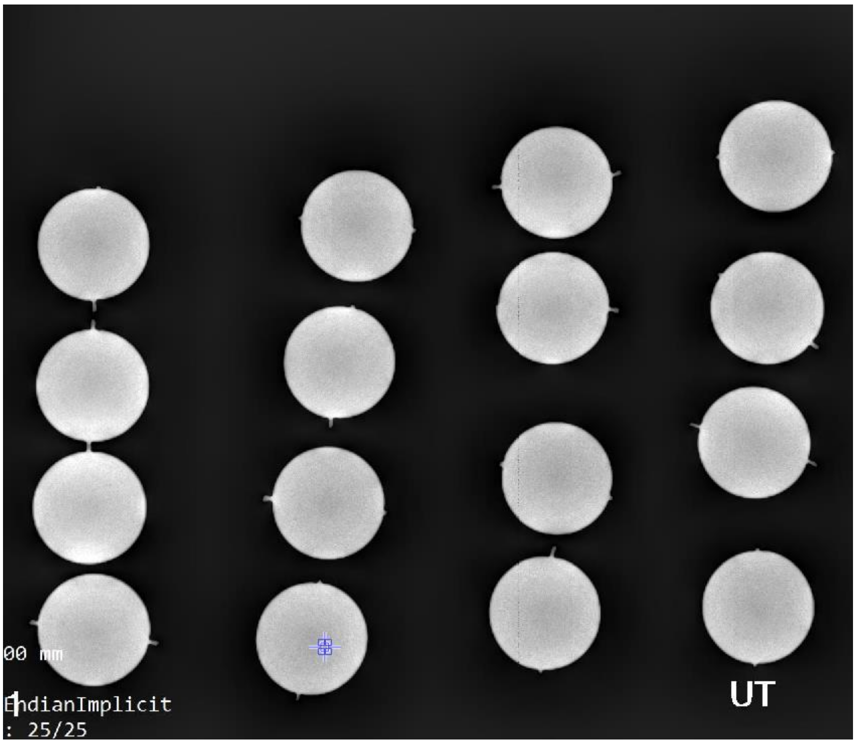


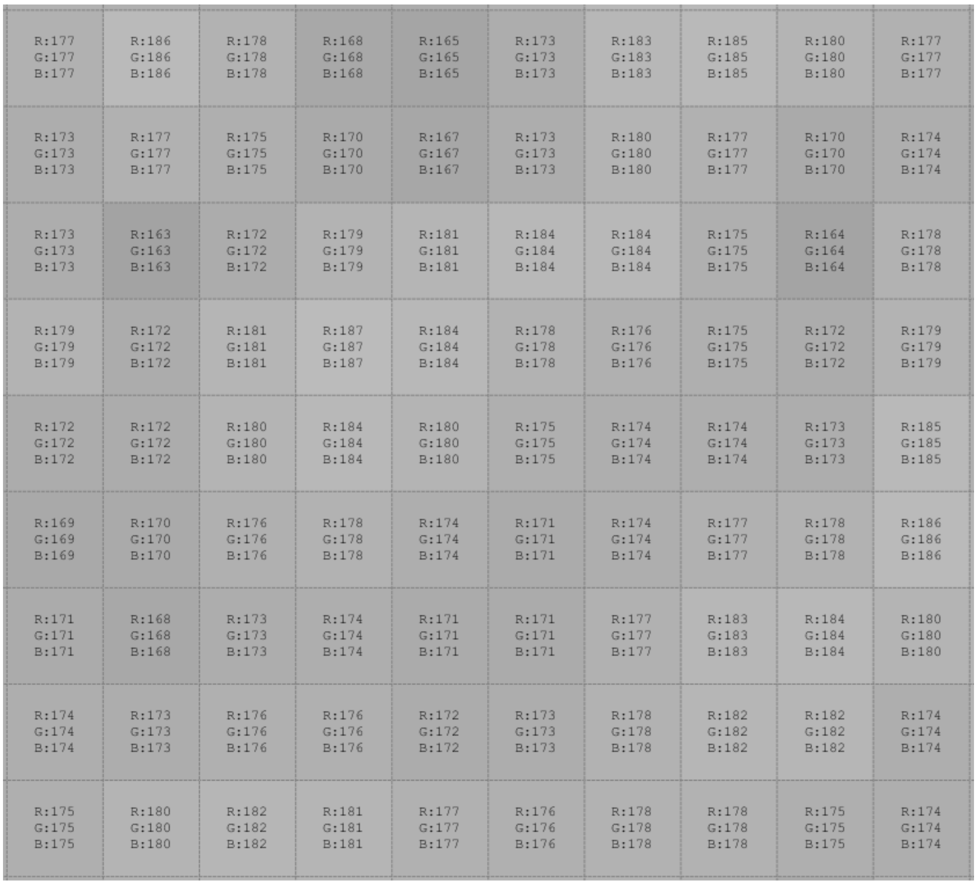
R:189 G:189 B:189	R:187 G:187 B:187	R:190 G:190 B:190	R:194 G:194 B:194	R:193 G:193 B:193	R:188 G:188 B:188	R:186 G:186 B:186	R:184 G:184 B:184	R:184 G:184 B:184	R:187 G:187 B:187	R:187 G:187 B:187	R:184 G:184 B:184
R:189 G:189 B:189	R:185 G:185 B:185	R:185 G:185 B:185	R:188 G:188 B:188	R:188 G:188 B:188	R:185 G:185 B:185	R:189 G:189 B:189	R:185 G:185 B:185	R:183 G:183 B:183	R:186 G:186 B:186	R:184 G:184 B:184	R:179 G:179 B:179
R:190 G:190 B:190	R:185 G:185 B:185	R:182 G:182 B:182	R:184 G:184 B:184	R:185 G:185 B:185	R:183 G:183 B:183	R:190 G:190 B:190	R:185 G:185 B:185	R:185 G:185 B:185	R:190 G:190 B:190	R:191 G:191 B:191	R:190 G:190 B:190
R:203 G:203 B:203	R:191 G:191 B:191	R:187 G:187 B:187	R:186 G:186 B:186	R:186 G:186 B:186	R:191 G:191 B:191	R:188 G:188 B:188	R:190 G:190 B:190	R:191 G:191 B:191	R:189 G:189 B:189	R:186 G:186 B:186	R:184 G:184 B:184
R:191 G:191 B:191	R:192 G:192 B:192	R:196 G:196 B:196	R:191 G:191 B:191	R:189 G:189 B:189	R:198 G:198 B:198	R:190 G:190 B:190	R:191 G:191 B:191	R:191 G:191 B:191	R:187 G:187 B:187	R:183 G:183 B:183	R:180 G:180 B:180
R:178 G:178 B:178	R:188 G:188 B:188	R:199 G:199 B:199	R:190 G:190 B:190	R:184 G:184 B:184	R:195 G:195 B:195	R:182 G:182 B:182	R:183 G:183 B:183	R:185 G:185 B:185	R:184 G:184 B:184	R:183 G:183 B:183	R:183 G:183 B:183
R:182 G:182 B:182	R:185 G:185 B:185	R:195 G:195 B:195	R:188 G:188 B:188	R:181 G:181 B:181	R:187 G:187 B:187	R:182 G:182 B:182	R:183 G:183 B:183	R:184 G:184 B:184	R:186 G:186 B:186	R:186 G:186 B:186	R:187 G:187 B:187
R:194 G:194 B:194	R:184 G:184 B:184	R:189 G:189 B:189	R:190 G:190 B:190	R:184 G:184 B:184	R:183 G:183 B:183	R:195 G:195 B:195	R:194 G:194 B:194	R:193 G:193 B:193	R:191 G:191 B:191	R:189 G:189 B:189	R:186 G:186 B:186
R:193 G:193 B:193	R:180 G:180 B:180	R:183 G:183 B:183	R:189 G:189 B:189	R:184 G:184 B:184	R:182 G:182 B:182	R:195 G:195 B:195	R:193 G:193 B:193	R:192 G:192 B:192	R:192 G:192 B:192	R:191 G:191 B:191	R:189 G:189 B:189
R:186 G:186 B:186	R:183 G:183 B:183	R:189 G:189 B:189	R:188 G:188 B:188	R:182 G:182 B:182	R:184 G:184 B:184	R:186 G:186 B:186	R:186 G:186 B:186	R:186 G:186 B:186	R:189 G:189 B:189	R:192 G:192 B:192	R:192 G:192 B:192
R:187 G:187 B:187	R:194 G:194 B:194	R:203 G:203 B:203	R:193 G:193 B:193	R:184 G:184 B:184	R:192 G:192 B:192	R:188 G:188 B:188	R:187 G:187 B:187	R:186 G:186 B:186	R:188 G:188 B:188	R:189 G:189 B:189	R:188 G:188 B:188



R:196 G:196 B:196	R:198 G:198 B:198	R:195 G:195 B:195	R:190 G:190 B:190	R:197 G:197 B:197	R:197 G:197 B:197	R:195 G:195 B:195	R:192 G:192 B:192	R:193 G:193 B:193	R:195 G:195 B:195
R:190 G:190 B:190	R:192 G:192 B:192	R:189 G:189 B:189	R:184 G:184 B:184	R:190 G:190 B:190	R:193 G:193 B:193	R:192 G:192 B:192	R:189 G:189 B:189	R:191 G:191 B:191	R:194 G:194 B:194
R:186 G:186 B:186	R:189 G:189 B:189	R:188 G:188 B:188	R:184 G:184 B:184	R:189 G:189 B:189	R:193 G:193 B:193	R:194 G:194 B:194	R:192 G:192 B:192	R:194 G:194 B:194	R:199 G:199 B:199
R:196 G:196 B:196	R:187 G:187 B:187	R:187 G:187 B:187	R:197 G:197 B:197	R:198 G:198 B:198	R:205 G:205 B:205	R:196 G:196 B:196	R:185 G:185 B:185	R:195 G:195 B:195	R:204 G:204 B:204
R:199 G:199 B:199	R:192 G:192 B:192	R:191 G:191 B:191	R:198 G:198 B:198	R:192 G:192 B:192	R:204 G:204 B:204	R:199 G:199 B:199	R:188 G:188 B:188	R:191 G:191 B:191	R:195 G:195 B:195
R:202 G:202 B:202	R:194 G:194 B:194	R:190 G:190 B:190	R:191 G:191 B:191	R:187 G:187 B:187	R:202 G:202 B:202	R:201 G:201 B:201	R:192 G:192 B:192	R:193 G:193 B:193	R:192 G:192 B:192
R:196 G:196 B:196	R:192 G:192 B:192	R:188 G:188 B:188	R:188 G:188 B:188	R:183 G:183 B:183	R:196 G:196 B:196	R:194 G:194 B:194	R:189 G:189 B:189	R:193 G:193 B:193	R:194 G:194 B:194
R:188 G:188 B:188	R:192 G:192 B:192	R:194 G:194 B:194	R:196 G:196 B:196	R:187 G:187 B:187	R:192 G:192 B:192	R:186 G:186 B:186	R:183 G:183 B:183	R:192 G:192 B:192	R:194 G:194 B:194
R:188 G:188 B:188	R:192 G:192 B:192	R:196 G:196 B:196	R:199 G:199 B:199	R:199 G:199 B:199	R:200 G:200 B:200	R:191 G:191 B:191	R:188 G:188 B:188	R:198 G:198 B:198	R:198 G:198 B:198

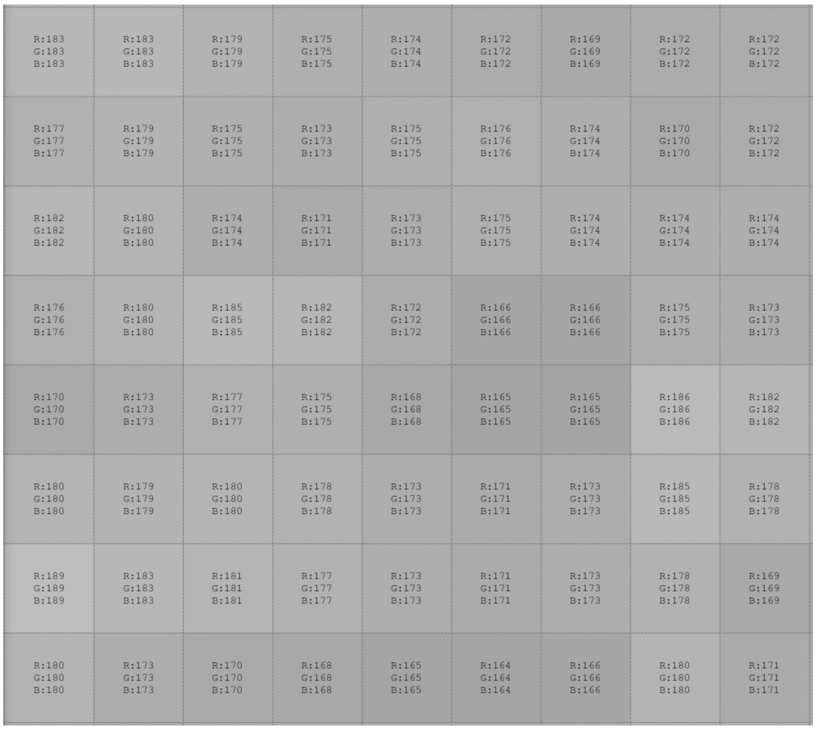
- Normalising sample results





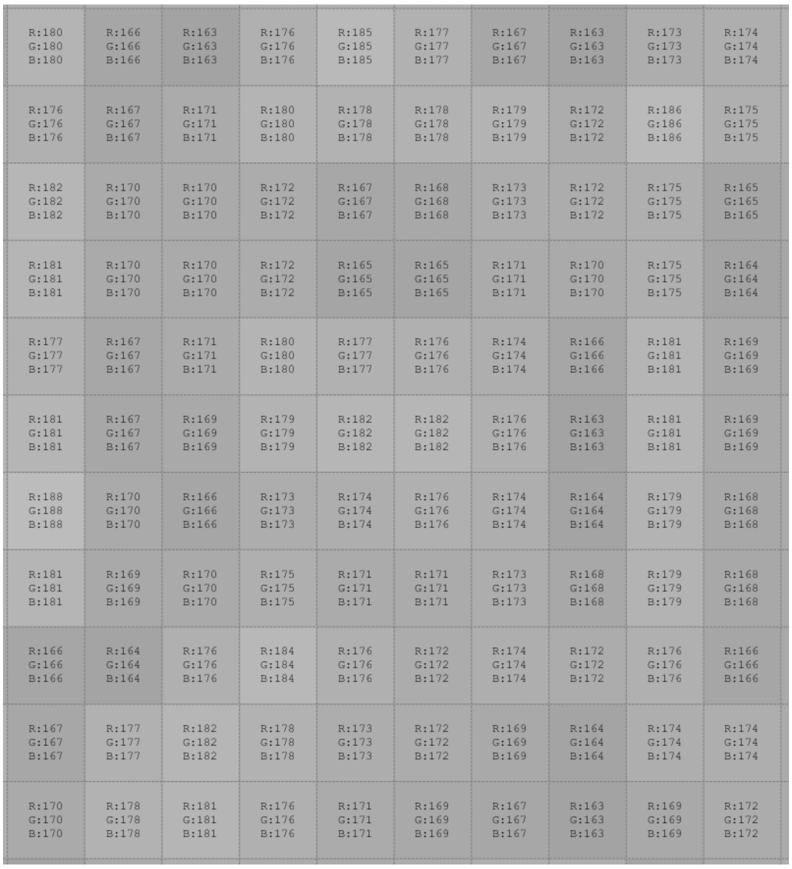
R:177 G:177 B:177	R:186 G:186 B:186	R:178 G:178 B:178	R:168 G:168 B:168	R:165 G:165 B:165	R:173 G:173 B:173	R:183 G:183 B:183	R:185 G:185 B:185	R:180 G:180 B:180	R:177 G:177 B:177
R:173 G:173 B:173	R:177 G:177 B:177	R:175 G:175 B:175	R:170 G:170 B:170	R:167 G:167 B:167	R:173 G:173 B:173	R:180 G:180 B:180	R:177 G:177 B:177	R:170 G:170 B:170	R:174 G:174 B:174
R:173 G:173 B:173	R:163 G:163 B:163	R:172 G:172 B:172	R:179 G:179 B:179	R:181 G:181 B:181	R:184 G:184 B:184	R:184 G:184 B:184	R:175 G:175 B:175	R:164 G:164 B:164	R:178 G:178 B:178
R:179 G:179 B:179	R:172 G:172 B:172	R:181 G:181 B:181	R:187 G:187 B:187	R:184 G:184 B:184	R:178 G:178 B:178	R:176 G:176 B:176	R:175 G:175 B:175	R:172 G:172 B:172	R:179 G:179 B:179
R:172 G:172 B:172	R:172 G:172 B:172	R:180 G:180 B:180	R:184 G:184 B:184	R:180 G:180 B:180	R:175 G:175 B:175	R:174 G:174 B:174	R:174 G:174 B:174	R:173 G:173 B:173	R:185 G:185 B:185
R:169 G:169 B:169	R:170 G:170 B:170	R:176 G:176 B:176	R:178 G:178 B:178	R:174 G:174 B:174	R:171 G:171 B:171	R:174 G:174 B:174	R:177 G:177 B:177	R:178 G:178 B:178	R:186 G:186 B:186
R:171 G:171 B:171	R:168 G:168 B:168	R:173 G:173 B:173	R:174 G:174 B:174	R:171 G:171 B:171	R:171 G:171 B:171	R:177 G:177 B:177	R:183 G:183 B:183	R:184 G:184 B:184	R:180 G:180 B:180
R:174 G:174 B:174	R:173 G:173 B:173	R:176 G:176 B:176	R:176 G:176 B:176	R:172 G:172 B:172	R:173 G:173 B:173	R:178 G:178 B:178	R:182 G:182 B:182	R:182 G:182 B:182	R:174 G:174 B:174
R:175 G:175 B:175	R:180 G:180 B:180	R:182 G:182 B:182	R:181 G:181 B:181	R:177 G:177 B:177	R:176 G:176 B:176	R:178 G:178 B:178	R:178 G:178 B:178	R:175 G:175 B:175	R:174 G:174 B:174

- After treatment

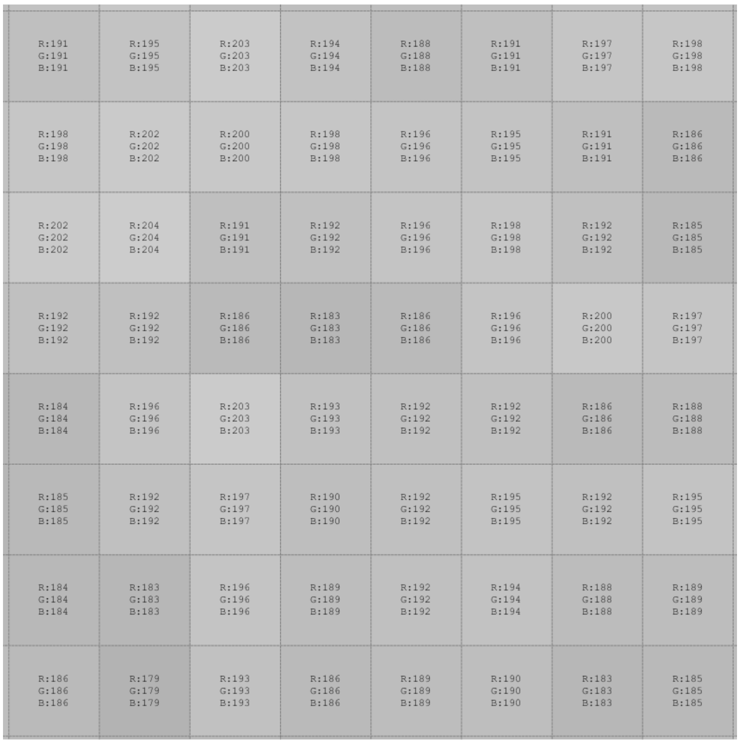


R:183 G:183 B:183	R:183 G:183 B:183	R:179 G:179 B:179	R:175 G:175 B:175	R:174 G:174 B:174	R:172 G:172 B:172	R:169 G:169 B:169	R:172 G:172 B:172	R:172 G:172 B:172
R:177 G:177 B:177	R:179 G:179 B:179	R:175 G:175 B:175	R:173 G:173 B:173	R:175 G:175 B:175	R:176 G:176 B:176	R:174 G:174 B:174	R:170 G:170 B:170	R:172 G:172 B:172
R:182 G:182 B:182	R:180 G:180 B:180	R:174 G:174 B:174	R:171 G:171 B:171	R:173 G:173 B:173	R:175 G:175 B:175	R:174 G:174 B:174	R:174 G:174 B:174	R:174 G:174 B:174
R:176 G:176 B:176	R:180 G:180 B:180	R:185 G:185 B:185	R:182 G:182 B:182	R:172 G:172 B:172	R:166 G:166 B:166	R:166 G:166 B:166	R:175 G:175 B:175	R:173 G:173 B:173
R:170 G:170 B:170	R:173 G:173 B:173	R:177 G:177 B:177	R:175 G:175 B:175	R:168 G:168 B:168	R:165 G:165 B:165	R:165 G:165 B:165	R:186 G:186 B:186	R:182 G:182 B:182
R:180 G:180 B:180	R:179 G:179 B:179	R:180 G:180 B:180	R:178 G:178 B:178	R:173 G:173 B:173	R:171 G:171 B:171	R:173 G:173 B:173	R:185 G:185 B:185	R:178 G:178 B:178
R:189 G:189 B:189	R:183 G:183 B:183	R:181 G:181 B:181	R:177 G:177 B:177	R:173 G:173 B:173	R:171 G:171 B:171	R:173 G:173 B:173	R:178 G:178 B:178	R:169 G:169 B:169
R:180 G:180 B:180	R:173 G:173 B:173	R:170 G:170 B:170	R:168 G:168 B:168	R:165 G:165 B:165	R:164 G:164 B:164	R:166 G:166 B:166	R:180 G:180 B:180	R:171 G:171 B:171

- Quenching in water

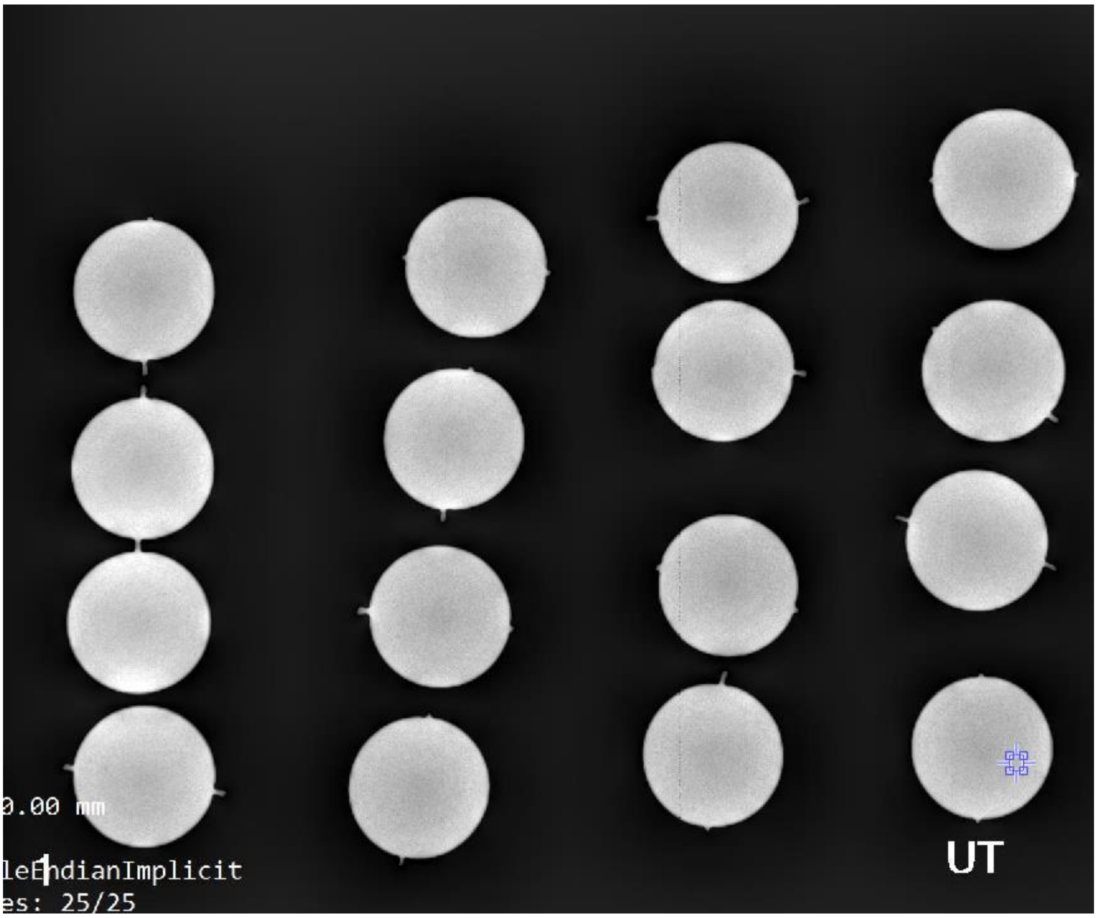


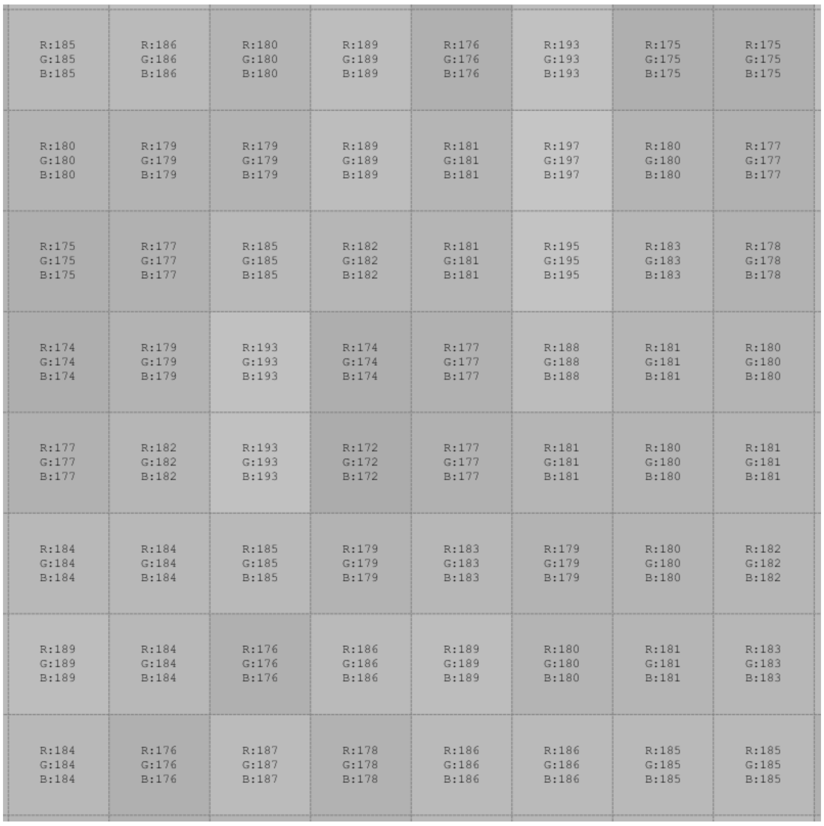
R:180 G:180 B:180	R:166 G:166 B:166	R:163 G:163 B:163	R:176 G:176 B:176	R:185 G:185 B:185	R:177 G:177 B:177	R:167 G:167 B:167	R:163 G:163 B:163	R:173 G:173 B:173	R:174 G:174 B:174
R:176 G:176 B:176	R:167 G:167 B:167	R:171 G:171 B:171	R:180 G:180 B:180	R:178 G:178 B:178	R:178 G:178 B:178	R:179 G:179 B:179	R:172 G:172 B:172	R:186 G:186 B:186	R:175 G:175 B:175
R:182 G:182 B:182	R:170 G:170 B:170	R:170 G:170 B:170	R:172 G:172 B:172	R:167 G:167 B:167	R:168 G:168 B:168	R:173 G:173 B:173	R:172 G:172 B:172	R:175 G:175 B:175	R:165 G:165 B:165
R:181 G:181 B:181	R:170 G:170 B:170	R:170 G:170 B:170	R:172 G:172 B:172	R:165 G:165 B:165	R:165 G:165 B:165	R:171 G:171 B:171	R:170 G:170 B:170	R:175 G:175 B:175	R:164 G:164 B:164
R:177 G:177 B:177	R:167 G:167 B:167	R:171 G:171 B:171	R:180 G:180 B:180	R:177 G:177 B:177	R:176 G:176 B:176	R:174 G:174 B:174	R:166 G:166 B:166	R:181 G:181 B:181	R:169 G:169 B:169
R:181 G:181 B:181	R:167 G:167 B:167	R:169 G:169 B:169	R:179 G:179 B:179	R:182 G:182 B:182	R:182 G:182 B:182	R:176 G:176 B:176	R:163 G:163 B:163	R:181 G:181 B:181	R:169 G:169 B:169
R:188 G:188 B:188	R:170 G:170 B:170	R:166 G:166 B:166	R:173 G:173 B:173	R:174 G:174 B:174	R:176 G:176 B:176	R:174 G:174 B:174	R:164 G:164 B:164	R:179 G:179 B:179	R:168 G:168 B:168
R:181 G:181 B:181	R:169 G:169 B:169	R:170 G:170 B:170	R:175 G:175 B:175	R:171 G:171 B:171	R:171 G:171 B:171	R:173 G:173 B:173	R:168 G:168 B:168	R:179 G:179 B:179	R:168 G:168 B:168
R:166 G:166 B:166	R:164 G:164 B:164	R:176 G:176 B:176	R:184 G:184 B:184	R:176 G:176 B:176	R:172 G:172 B:172	R:174 G:174 B:174	R:172 G:172 B:172	R:176 G:176 B:176	R:166 G:166 B:166
R:167 G:167 B:167	R:177 G:177 B:177	R:182 G:182 B:182	R:178 G:178 B:178	R:173 G:173 B:173	R:172 G:172 B:172	R:169 G:169 B:169	R:164 G:164 B:164	R:174 G:174 B:174	R:174 G:174 B:174
R:170 G:170 B:170	R:178 G:178 B:178	R:181 G:181 B:181	R:176 G:176 B:176	R:171 G:171 B:171	R:169 G:169 B:169	R:167 G:167 B:167	R:163 G:163 B:163	R:169 G:169 B:169	R:172 G:172 B:172



R:191 G:191 B:191	R:195 G:195 B:195	R:203 G:203 B:203	R:194 G:194 B:194	R:188 G:188 B:188	R:191 G:191 B:191	R:197 G:197 B:197	R:198 G:198 B:198
R:198 G:198 B:198	R:202 G:202 B:202	R:200 G:200 B:200	R:198 G:198 B:198	R:196 G:196 B:196	R:195 G:195 B:195	R:191 G:191 B:191	R:186 G:186 B:186
R:202 G:202 B:202	R:204 G:204 B:204	R:191 G:191 B:191	R:192 G:192 B:192	R:196 G:196 B:196	R:198 G:198 B:198	R:192 G:192 B:192	R:185 G:185 B:185
R:192 G:192 B:192	R:192 G:192 B:192	R:186 G:186 B:186	R:183 G:183 B:183	R:186 G:186 B:186	R:196 G:196 B:196	R:200 G:200 B:200	R:197 G:197 B:197
R:184 G:184 B:184	R:196 G:196 B:196	R:203 G:203 B:203	R:193 G:193 B:193	R:192 G:192 B:192	R:192 G:192 B:192	R:186 G:186 B:186	R:188 G:188 B:188
R:185 G:185 B:185	R:192 G:192 B:192	R:197 G:197 B:197	R:190 G:190 B:190	R:192 G:192 B:192	R:195 G:195 B:195	R:192 G:192 B:192	R:195 G:195 B:195
R:184 G:184 B:184	R:183 G:183 B:183	R:196 G:196 B:196	R:189 G:189 B:189	R:192 G:192 B:192	R:194 G:194 B:194	R:188 G:188 B:188	R:189 G:189 B:189
R:186 G:186 B:186	R:179 G:179 B:179	R:193 G:193 B:193	R:186 G:186 B:186	R:189 G:189 B:189	R:190 G:190 B:190	R:183 G:183 B:183	R:185 G:185 B:185

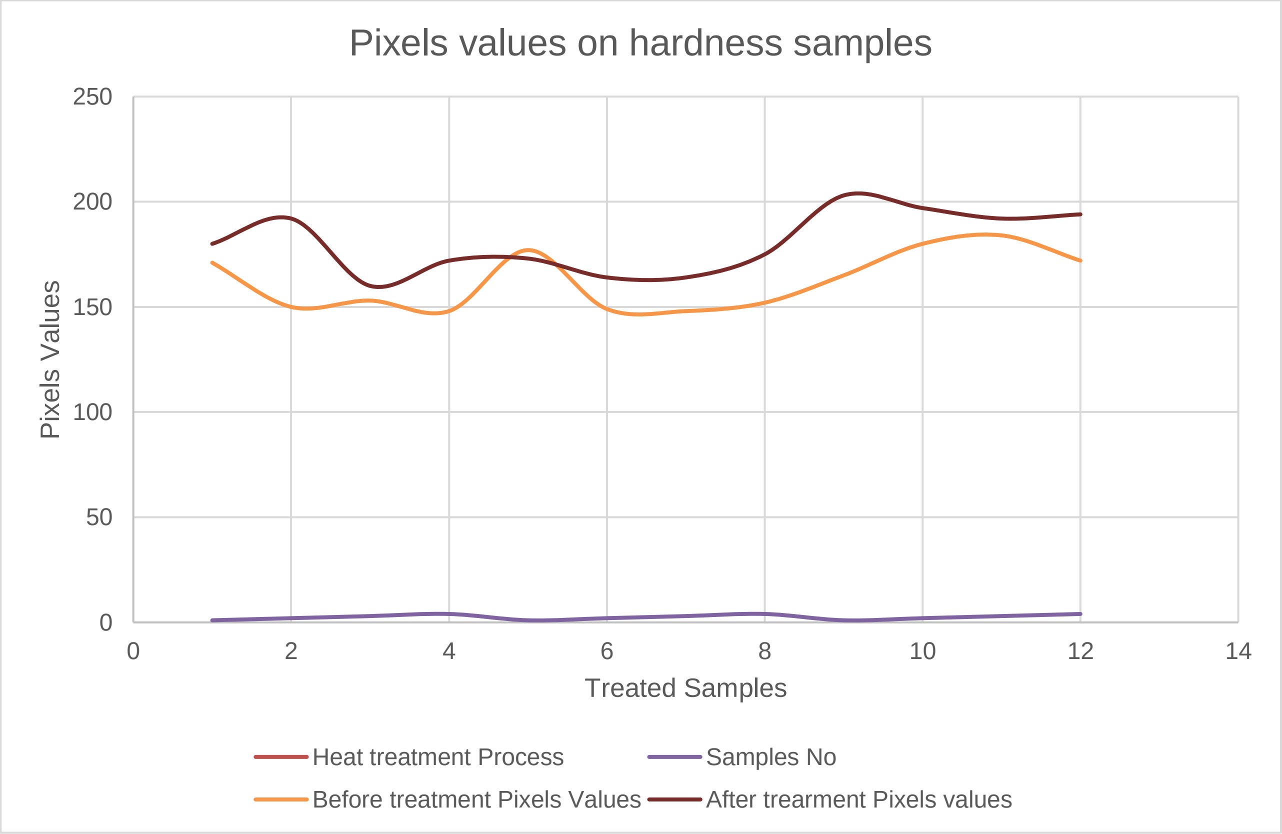
- Untreated samples





R:185 G:185 B:185	R:186 G:186 B:186	R:180 G:180 B:180	R:189 G:189 B:189	R:176 G:176 B:176	R:193 G:193 B:193	R:175 G:175 B:175	R:175 G:175 B:175
R:180 G:180 B:180	R:179 G:179 B:179	R:179 G:179 B:179	R:189 G:189 B:189	R:181 G:181 B:181	R:197 G:197 B:197	R:180 G:180 B:180	R:177 G:177 B:177
R:175 G:175 B:175	R:177 G:177 B:177	R:185 G:185 B:185	R:182 G:182 B:182	R:181 G:181 B:181	R:195 G:195 B:195	R:183 G:183 B:183	R:178 G:178 B:178
R:174 G:174 B:174	R:179 G:179 B:179	R:193 G:193 B:193	R:174 G:174 B:174	R:177 G:177 B:177	R:188 G:188 B:188	R:181 G:181 B:181	R:180 G:180 B:180
R:177 G:177 B:177	R:182 G:182 B:182	R:193 G:193 B:193	R:172 G:172 B:172	R:177 G:177 B:177	R:181 G:181 B:181	R:180 G:180 B:180	R:181 G:181 B:181
R:184 G:184 B:184	R:184 G:184 B:184	R:185 G:185 B:185	R:179 G:179 B:179	R:183 G:183 B:183	R:179 G:179 B:179	R:180 G:180 B:180	R:182 G:182 B:182
R:189 G:189 B:189	R:184 G:184 B:184	R:176 G:176 B:176	R:186 G:186 B:186	R:189 G:189 B:189	R:180 G:180 B:180	R:181 G:181 B:181	R:183 G:183 B:183
R:184 G:184 B:184	R:176 G:176 B:176	R:187 G:187 B:187	R:178 G:178 B:178	R:186 G:186 B:186	R:186 G:186 B:186	R:185 G:185 B:185	R:185 G:185 B:185

- Comparison of all pixel's values



Thank You.