# MM208 Report

## Name: Daksh Garg

## Entry No.: 2023MMB1410

**AIM: Heat Treatment of Low-carbon Steel**

## Index:

## 1.Introduction to Heat treatment:

Without changing their shape, heat treatment is a technique used to change the mechanical and physical characteristics of metals and alloys. It entails raising the material's temperature to a predetermined level, holding it there for a predetermined amount of time (the soak time), and then carefully cooling it down. Hardness, ductility, strength, and resistance to temperature can all be improved by this process.

## Types of heat treatment:

**1. Annealing:** Reduces internal stresses and increases the material's ductility, softening it. It has to do with furnace cooling.

**2. Hardening:** This process raises the material's hardness by heating it above its critical temperature and then quickly cooling it (quenching).

**3.Tempering:** After hardening, the material is heated to a lower temperature and then gradually cooled to reduce brittleness.

**4.Normalizing:** Like annealing, but with air cooling as opposed to furnace cooling.

**5.Stress Relieving:** Reduces internal tensions without appreciably changing other characteristics.

**6.Case Hardening:** Preserves a robust core while increasing surface hardness.

## Importance of Heat Treatment:

**1.Improved Mechanical properties:** Enhances Strength, Ductility and Hardness.

**2. Enhanced Durability:** Enhances resistance to corrosion and wear.

**3.Versatility:** Suitable for a range of metals and alloys, such as titanium, steel, and aluminium.

4. **Crucial in Manufacturing:** Important for sectors like construction, automotive, and aerospace.

In metal fabrication, heat treatment is an essential step that gives materials the ability to acquire particular qualities for best performance in various applications.

# 2.Material and Application of Workpiece:

## 2.1 Material selection:

Low-carbon steel with a carbon content between 0.05% and 0.25% was the material used in this experiment. Iron and carbon make up the majority of low-carbon steel, with trace amounts of additional alloying elements. Because of its exceptional ductility, weldability, and machinability, it finds extensive use. Hardness, strength, and toughness are all impacted by the carbon content, which has a major impact on mechanical properties.

## 2.2 Low-Carbon Steel Properties:

Excellent machinability, moderate strength with high toughness, excellent formability and weldability, and use in general fabrication, pipes, construction frameworks, and automobile body panels

## 2.3 Application of low carbon steel:

Because of its exceptional ductility, weldability, and affordability, low carbon steel—also referred to as mild steel—is used extensively in a variety of industries.

**1.Building and Facilities:**
utilized in building and bridge reinforcing bars, frames, and structural beams.

**2.Automobile Sector:**
Because of its formability and weldability, it is found in engine parts and automobile bodies.

**3.Equipment and Machinery:**
Because of its affordability and simplicity of fabrication, it is preferred for bolts, nuts, gears, and support structures.

**4.Consumer Goods**:
utilized in home appliances such as refrigerators and washing machines.

**5.**also present in shelving units and furniture frames.

**6.Tubing and Piping:**
Often used for systems with moderate temperatures and low pressure lines.

**7.Medical equipment and cookware:**
utilized in medical equipment and cookware because of its strength and

## 3.Experimental Procedure:

### 3.1 Heating the Sample:

Steel samples were placed in a furnace and heated to a temperature of 1100°C. This temperature ensured complete transformation of the microstructure to the austenitic phase, where iron atoms rearrange into a face-centred cubic (FCC) structure, making the material more responsive to cooling processes.

### 3.2 Procedures for Heat Treatment:

The samples were exposed to various cooling techniques after they attained the appropriate temperature:

**1.Quenching:** By submerging the heated steel sample in water or oil, it was quickly cooled. A hard but brittle structure known as martensitic was formed as a result of this abrupt cooling.

**2. Annealing:** By turning off the heat, the steel was allowed to cool gradually inside the furnace. The steel became softer and more ductile as a result of the coarse ferrite and pearlite structure that was created during this process.

**3.Normalizing:** After being heated, the steel was taken out of the furnace and given time to cool naturally in the air. Strength and toughness were balanced in the resulting refined ferrite-pearlite structure.

### 3.3 Microstructural Analysis Sample Preparation:

The following procedures were used to prepare the treated samples in order to analyze the microstructural changes:

**1.Sandpaper Surface Grinding:** To eliminate oxidation layers and surface irregularities, the surface is polished using progressively finer grades of sandpaper.

**2.Cloth polishing:** To create a smooth, reflective surface for microscopic inspection, additional polishing is done using a fine abrasive compound.

### 3.4 Analysis of Microstructure:

A metallurgical microscope was used to view the internal structures of the polished samples:

**1. Quenched steel:** Contributed to its extreme hardness and brittleness by exhibiting a needle-like martensitic structure.

**2.Annealed steel:** Displayed a coarse, equiaxed ferrite and pearlite structure, suggesting decreased hardness and increased ductility.

**3.Normalized steel:** Displayed a refined ferrite-pearlite structure that balanced toughness and strength.

### 3.5 Hardness Testing:

The hardness of each sample was measured using a hardness testing machine. The results followed the expected trend:

**1.Quenched sample**: Highest hardness due to martensitic transformation.

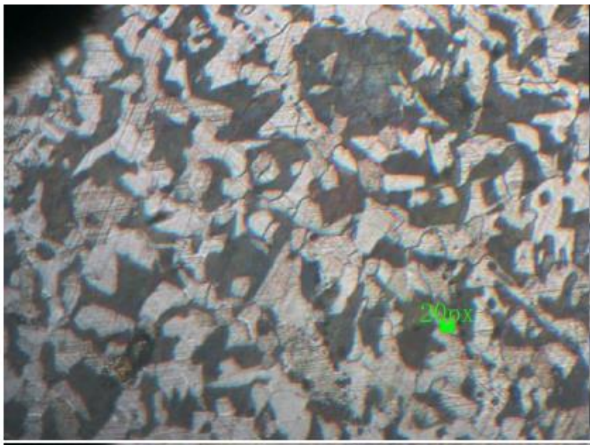
**2.Annealed sample**: Lowest hardness due to softening and stress relief.

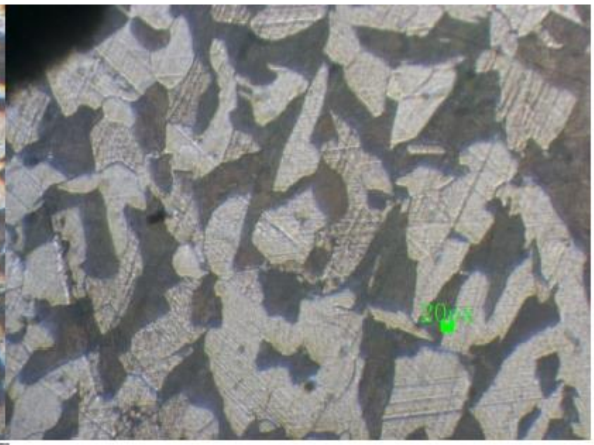
**3.Normalized sample**: Intermediate hardness with balanced mechanical properties.

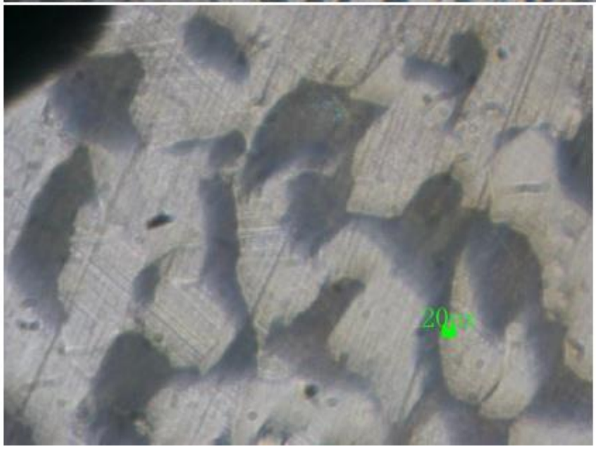
## 4. Results:

### 4.1 Microstructure Observation:

**(A) Annealed Sample:**








**Observations on Structure (Annealed Samples)**

**1. Grain Structure:**

1.The ferrite and pearlite structure in the pictures is coarse and equiaxed, which is characteristic of annealed low-carbon steel.
2.Because of the slow cooling, which gives atomic diffusion enough time, the grains are comparatively large.
3. A soft and ductile microstructure is indicated by the distinct ferrite (light regions) and pearlite (darker regions).

**2. Grain Boundaries:**

1.The grain boundaries appear smooth and well-distributed, suggesting reduced internal stresses.

2.No signs of martensitic or bainitic structures, confirming complete annealing.

**3.Pearlite Distribution:**

1.The pearlite regions are coarsely spaced, meaning slower cooling allowed for thicker cementite lamellae.

2.This structure contributes to enhanced ductility and machinability while reducing hardness.

**Mechanical Consequences**:
**1. Reduction of Hardness:**

1. Annealing considerably lowers hardness in comparison to quenched steel.
2. This facilitates the material's shaping and machining.

**2. Greater Ductility:**

1.The steel can withstand deformation without breaking because of the soft ferritic structure's increased ductility.
2. This helps with forming processes like deep drawing and bending.

**3. Better Machinability:**

1.Tools wear down less during machining when their hardness is decreased.
2. The consistent microstructure results in an improved surface finish.

**4. Stress Relief:**

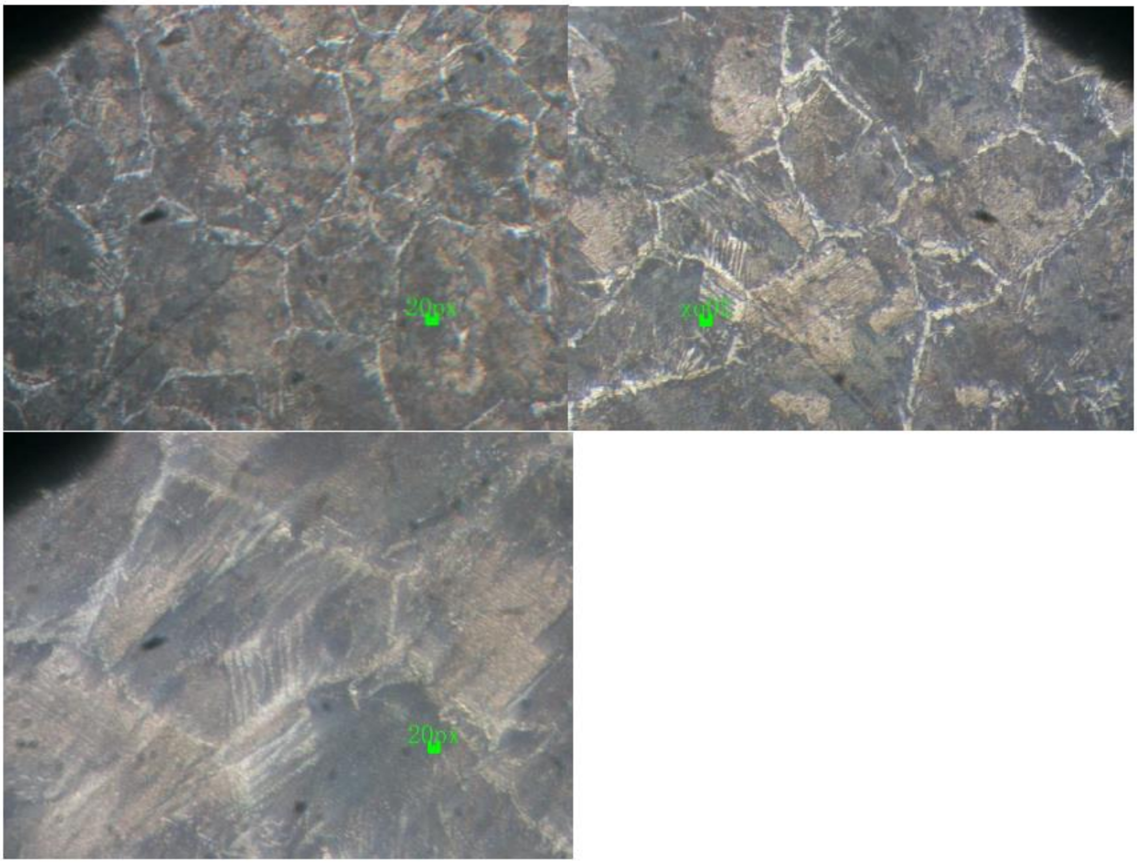
1. Internal stresses brought on by earlier thermal treatments or mechanical work are reduced.
2.As a result, there is less chance of warping or cracking during later operations.

**5.Lower Strength Compared to Quenched or Normalized Steel:**

1. While toughness improves, the yield and tensile strength decrease compared to quenched steel.

2.This makes annealed steel suitable for applications where high strength is not the primary requirement.

**(B) Normalized Sample:**




**Observations on Structure (Normalized sample)**
**1. Grain Structure:**

1.A refined ferrite-pearlite structure, typical of normalized low-carbon steel, is visible in the pictures.
2.The mechanical properties are improved because the grains are finer and more uniform than in annealed samples.
3.The distribution of pearlite (darker regions) and ferrite (lighter regions) is uniform.

**2. Grain Boundaries:**
1.A balanced cooling rate is indicated by well-defined and finer grain boundaries.
2.In comparison to annealed steel, the reduced grain size results in greater strength and toughness.

**3. Pearlite Distribution:**
1.Compared to annealed steel, the pearlite regions are more uniformly spaced and refined.
2.The finer, more lamellar structure results in moderate strength and hardness.

**Mechanical Consequences**
**1. Increased Toughness and Strength:**
1. Normalization produces greater yield strength and tensile strength than annealed steel.
2.Strength and ductility are well-balanced by the refined microstructure.

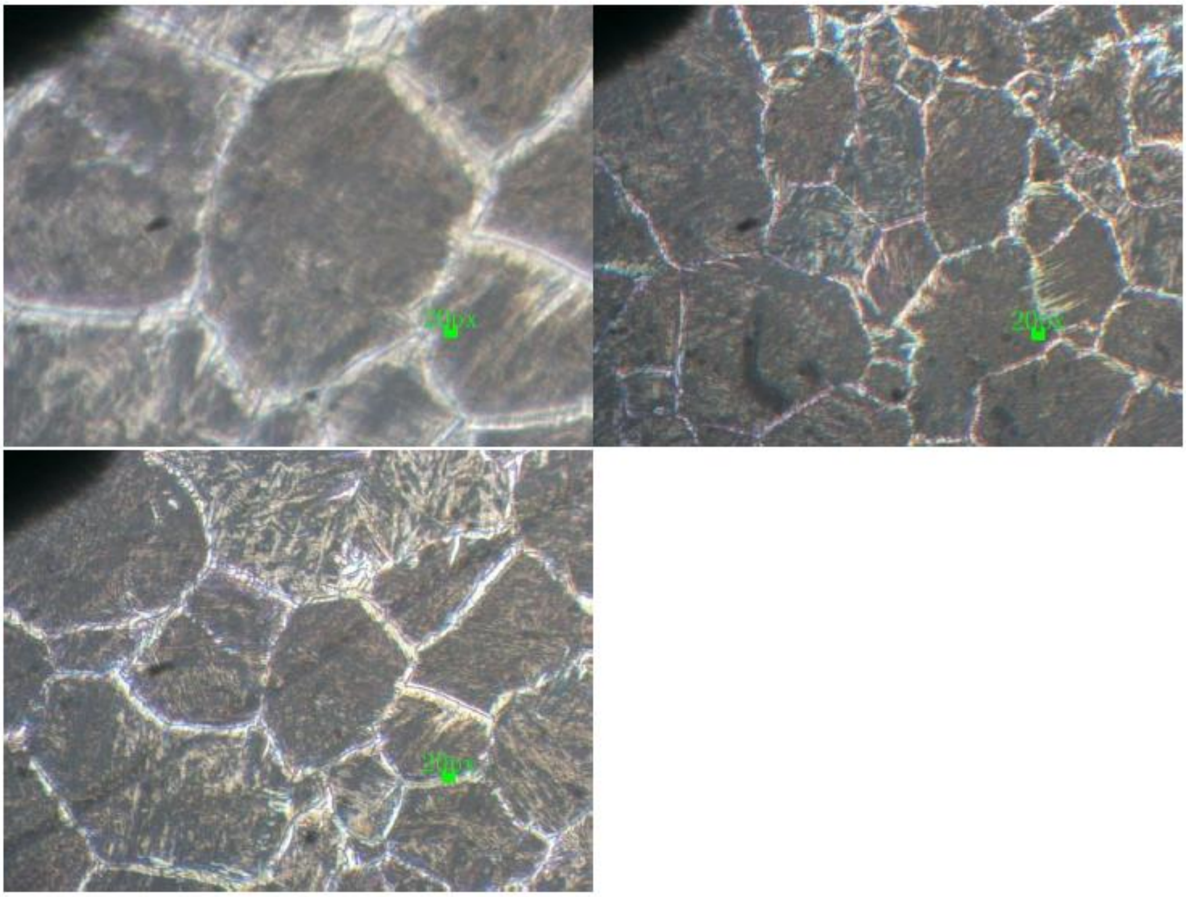
**2.Improved Toughness Compared to Quenched Steel:**
1.Enhanced Hardness Normalized steel is more resilient to impact loading than quenched steel because it is stronger and less brittle.
2.For structural applications that need shock absorption, this is advantageous.

**3. Moderate Hardness:**
1.The hardness is lower than quenched steel but higher than annealed steel.
2.Because of this, normalized steel can be used in situations where excessive brittleness is undesirable but wear resistance is crucial.

**4. Mechanical Property Uniformity:**
1.The microstructure is more uniform as a result of the controlled cooling in air, which results in consistent mechanical properties.
2.This makes it perfect for parts that need to be strong and easily machined.

**5. Lower Internal Stresses:**
**1.** Normalized steel has lower residual stresses, which reduces the chance of warping or cracking, in contrast to quenched steel, which develops high internal stresses.

**(C) Quenched Sample:**



**Observations on Structure**
**1. Grain Structure:**
1. As is typical of quenched steel, the microstructure displays a needle-like martensitic structure.
2. Because of the abrupt cooling, the grains appear greatly elongated and distorted, suggesting rapid transformation.
3. There are hardly any areas of ferrite or pearlite visible, indicating that martensite predominates.

**2. Martensitic Formation:**
1. The quenched samples exhibit fine, needle-shaped, acicular martensite, which adds to their exceptionally high hardness.
2.Rapid cooling from the austenitic phase is suggested by the absence of diffusional transformations.

**3. Grain Boundaries:**
1.The rapid phase transformation is indicated by the less distinct grain boundaries.
2.The abrupt volume change that occurs during martensite formation results in high residual stresses.

**Mechanical Consequences**
**1. High Strength and Hardness:**

1.The hardness and tensile strength are greatly increased by the martensitic structure.
2.Because of this, quenched steel is perfect for wear-resistant products like gears and cutting tools.

**2. Brittleness:**
1. The material becomes extremely brittle as ductility is drastically decreased while hardness is maximized.
2.This indicates that under impact or tensile loading, quenched steel is vulnerable to abrupt fracture.

**3. Distortion and Remaining Stresses:**
1. High internal stresses brought on by the quick cooling raise the possibility of warping or cracking.
2. To reduce these stresses and increase toughness, post-quenching tempering is frequently necessary.

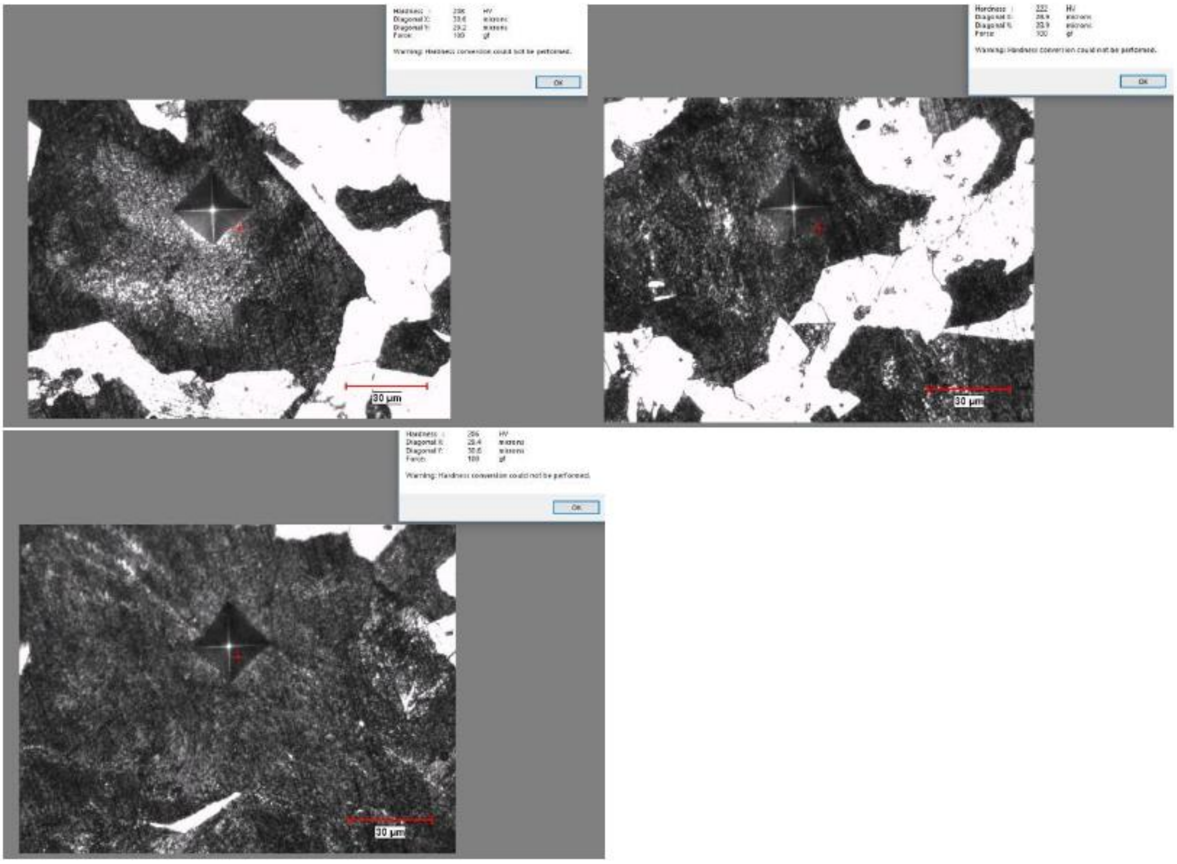
**4. Low Toughness:**
1.The impact resistance of quenched steel is significantly lower than that of annealed or normalized steel.
2. It is not appropriate for uses that call for shock absorption or flexibility.

**5. The necessity of tempering:**
1. Quenched steel is usually tempered at moderate temperatures to increase toughness while maintaining hardness.
2. By partially transforming martensite into tempered martensite, this process enhances

mechanical performance.

## 4.2 Hardness Test Observation (Vickers Hardness Test):

### (A) Annealed Sample:




## Hardness and Diagonal Measurements:

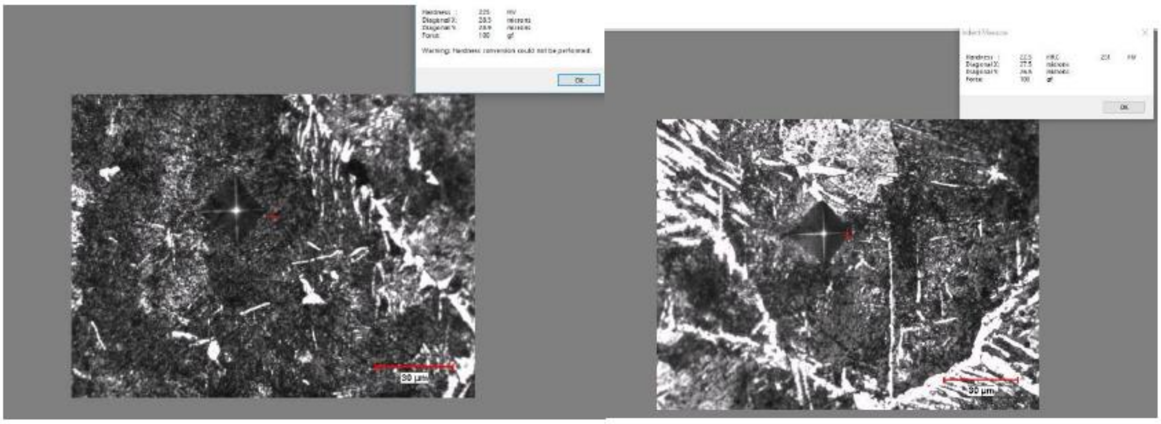
**Hardness and Diagonal Measurements:**

1. **A1:**
    - Hardness: 208 HV
    - Diagonal X: 30.6 µm
    - Diagonal Y: 29.2 µm
2. **A2:**
    - Hardness: 222 HV
    - Diagonal X: 28.9 µm
    - Diagonal Y: 28.9 µm

3. **A3:**
    - Hardness: 206 HV
    - Diagonal X: 29.4 µm
    - Diagonal Y: 30.6 µm

**Brief Analysis:** Because internal stresses and grain coarsening have decreased, the annealed samples show comparatively low hardness values, suggesting a softer microstructure. A more equiaxed grain structure, characteristic of annealing, which increases ductility but decreases strength, is suggested by the micrographs. Localized variations in grain size and phase distribution could be the cause of the small variation in hardness values.

**(B) Normalized Sample:**



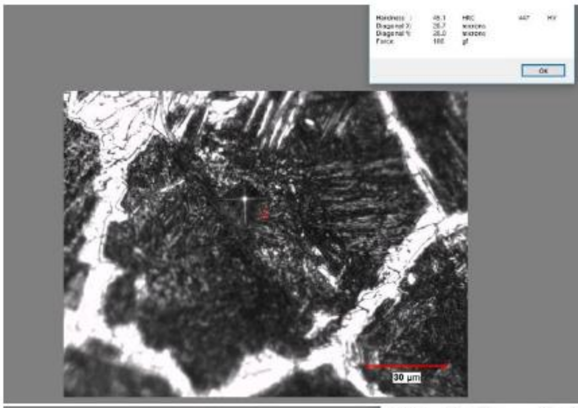
**Hardness and Diagonal Distance Measurements:**

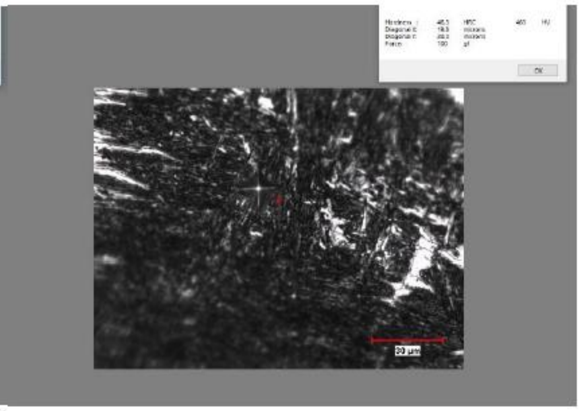
1. **N1**
   - Hardness: 225 HV
   - Diagonal X: 28.5 microns
   - Diagonal Y: 28.9 microns
   - Force: 100 gf
2. **N2**
   - Hardness: 251 HV
   - Diagonal X: 27.5 microns
   - Diagonal Y: 26.8 microns
   - Force: 100 gf

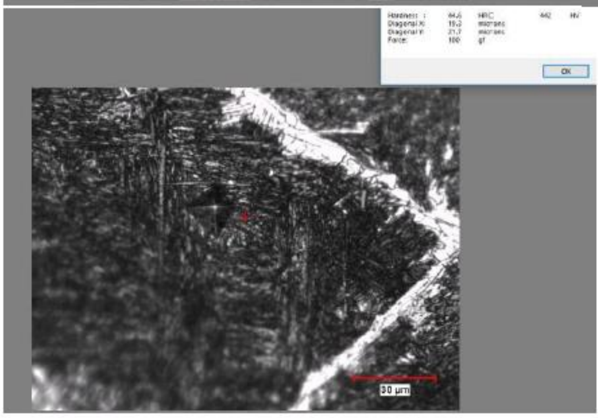
**Brief Analysis:**
1.the hardness values indicate that the material is generally uniform, with minor variances across various normalized samples.

2. Sample Norm-2 has the highest hardness (251 HV), which might be a sign of a distinct phase distribution or a slightly finer microstructure than the other two.
3. There is no significant variation in hardness, suggesting stability in material properties.
4. the diagonal distances are always close, indicating consistent indentation sizes, suggesting good uniformity in mechanical properties across samples and the normalization process appears to be successful.

**(C)Quenched Sample:**







**Hardness and Diagonal Distance Measurements:**

1. **Q1:**
    - Hardness: 447 HV (45.1 HRC)
    - Diagonal X: 20.7 µm
    - Diagonal Y: 20.0 µm
2. **Q2:**
    - Hardness: 463 HV (46.3 HRC)
    - Diagonal X: 19.8 µm
    - Diagonal Y: 20.3 µm
3. **Q3:**
    - Hardness: 442 HV (44.6 HRC)
    - Diagonal X: 19.3 µm
    - Diagonal Y: 21.7 µm

**Brief Analysis:**
these pictures show quenched microstructures with hardness values ranging from 442 to 463 HV, which, depending on the quenching conditions, indicate either a martensitic or bainitic

microstructure. The small variances in diagonal measurements point to some hardness inhomogeneity, which is probably caused by retained austenite, microstructural variations, or slight variations in quenching efficiency.

Cracks or bright phase boundaries may indicate microstructural stresses or carbide formation, which may require additional tempering for improved toughness. The hardness values show that the material has high strength and wear resistance, which is typical after rapid quenching.

## 5.Discussion:

The microstructure and mechanical characteristics of heat-treated low-carbon steel are significantly impacted by quenching, annealing, and normalizing, as shown by the experimental analysis of the material. Because of the creation of a martensitic structure, which was incredibly strong but also brought about brittleness and internal stresses, quenching produced the highest hardness. A coarse ferrite-pearlite structure was created by annealing, which greatly decreased hardness while increasing ductility and machinability. Normalization produced a refined ferrite-pearlite distribution and a balanced microstructure, resulting in enhanced toughness and moderate hardness. As anticipated, the hardness measurements showed that annealed steel had the lowest hardness (206–222 HV), normalized steel had a moderate hardness (225–251 HV), and quenched steel had the highest hardness (442–463 HV). Since phase changes and grain refinement had a direct impact on mechanical behavior, the microstructural observations corroborated these findings.

## 6.Conclusion:

This study demonstrates how various heat treatment techniques affect the mechanical characteristics and microstructure of low-carbon steel. Normalizing produced a balanced microstructure with moderate hardness and enhanced toughness, annealing softened the material while improving ductility, and quenching produced maximum hardness but added brittleness. These changes were validated by microstructural observations and hardness measurements. The results highlight how crucial it is to choose the right heat treatment techniques for particular engineering applications based on the required material properties. In order to achieve even more control over mechanical properties, future research could concentrate on tempering quenched samples to maximize toughness while maintaining high hardness or on fine-tuning heat treatment parameters.