UNIVERSITY OF JOHANNESBURG

Department of Mechanical Engineering Science

PRACTICAL 2: MICROSCOPIC EXAMINATION

Hardness Testing and Microstructural Analysis of Three Steel Specimens

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I, Kagiso Letsholo (Student Number: 222032860), declared that this report was my own, unaided work. I have referenced correctly and in full all sources that I have used. I understand that plagiarism is a serious form of academic dishonesty and that the necessary disciplinary action would be taken against me should this declaration be found to be false.

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Abstract

This practical was undertaken to investigate the relationship between the microstructure and the mechanical strength of three steel specimens, namely an as-received low carbon steel (EN3/1015, 0.15% C), a plastically deformed (work hardened) sample of the same low carbon steel, and an as-received medium carbon steel (EN8/1040, 0.4% C). The hardness of each specimen was measured using a Rockwell hardness tester on the A scale, after which the specimens were mounted, ground, polished and etched with a 5% nitric acid in ethanol solution to reveal their microstructures. The specimens were then examined under a metallurgical microscope. The as-received EN3 specimen recorded the lowest average hardness of 45.67 HRA, followed by the work hardened EN3 specimen at 58.33 HRA, while the EN8 specimen recorded the highest average hardness of 65.67 HRA. These results were found to be consistent with the microstructures observed, with the higher hardness values corresponding to a greater proportion of the harder pearlite phase and, in the case of the work hardened specimen, a deformed grain structure.

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1. Aim of Practical

The aim of this practical session was to investigate the strength of three selected steel specimens by means of a hardness test, and to relate the measured hardness values to the microstructure of each specimen as observed under a metallurgical microscope.

2. Introduction

Steel is an alloy of iron and carbon, and its mechanical properties are strongly dependent on both its carbon content and its microstructure [2]. At room temperature, pure iron exists predominantly in the body centred cubic (BCC) crystal structure, known as ferrite (α-iron), which is soft and ductile. As the carbon content of a steel is increased, a greater proportion of iron carbide (Fe_3C), also known as cementite, forms. Ferrite and cementite combine in a lamellar arrangement to form pearlite, a two-phase microconstituent that is significantly harder and stronger than ferrite alone [2].

Below the eutectoid carbon content, steels consist of a mixture of proeutectoid ferrite and pearlite, with the proportion of pearlite increasing as the carbon content increases [2]. Consequently, medium carbon steels such as EN8 (1040) are expected to contain a greater fraction of pearlite than low carbon steels such as EN3 (1015), and are therefore harder and stronger.

Hardness is a measure of a material's resistance to localised plastic deformation, and is commonly used as an indirect indicator of strength [2]. In this practical, hardness was measured using the Rockwell hardness scale (A scale), in which a diamond indenter is pressed into the specimen under a specified load and the depth of penetration is converted into a hardness number [1].

Plastic deformation at room temperature, referred to as cold work or work hardening, increases the dislocation density within the metal's crystal structure [2]. As dislocations multiply and interact, further dislocation motion is impeded, which increases the hardness and strength of the material while reducing its ductility [2]. This effect is investigated in this practical by comparing an as-received EN3 specimen with an EN3 specimen that had been plastically deformed.

To reveal the microstructure of a metal under a microscope, the surface of the specimen must first be ground and polished to a mirror-like, scratch-free finish [1]. The polished surface is then etched with a mild acid solution, which reacts at different rates with the different phases present and with the grain boundaries, producing contrast that allows the microstructure to be observed and photographed under magnification [1].

3. Results

3.1 Hardness Test Results

The Rockwell hardness (A scale) of each of the three specimens was measured, and the results are presented in Table 1.

Table 1: Rockwell hardness (A scale) test results for the three steel specimens

Specimen	Reading 1 (HRA)	Reading 2 (HRA)	Reading 3 (HRA)	Average (HRA)
EN3 (1015), 0.15% C – as received	44	46	45	45.67
EN3 (1015), 0.15% C – work hardened	60	57	58	58.33
EN8 (1040), 0.4% C – as received	64	68	65	65.67

It was found that the as-received EN3 specimen recorded the lowest average hardness, the work hardened EN3 specimen recorded an intermediate hardness, and the EN8 specimen recorded the highest average hardness of the three specimens tested.

3.2 Microstructure Observations

Following etching, the microstructure of each specimen was examined under a metallurgical microscope. A summary of the phases observed is given in Table 2, and representative micrographs are shown in Figures 1 to 3.

Table 2: Summary of microstructural observations for the three steel specimens

Specimen	Phases Observed	General Description
EN3 (1015), as received	Ferrite (majority), pearlite (minority)	Light, equiaxed ferrite grains with dark pearlite distributed mainly along grain boundaries
EN3 (1015), work hardened	Ferrite (majority), pearlite (minority), deformed grains	Grain structure elongated/distorted in the direction of deformation compared with the as-received specimen
EN8 (1040), as received	Ferrite and pearlite, with a markedly greater proportion of pearlite	Substantially larger dark areas of pearlite relative to the EN3 specimens, reflecting the higher carbon content

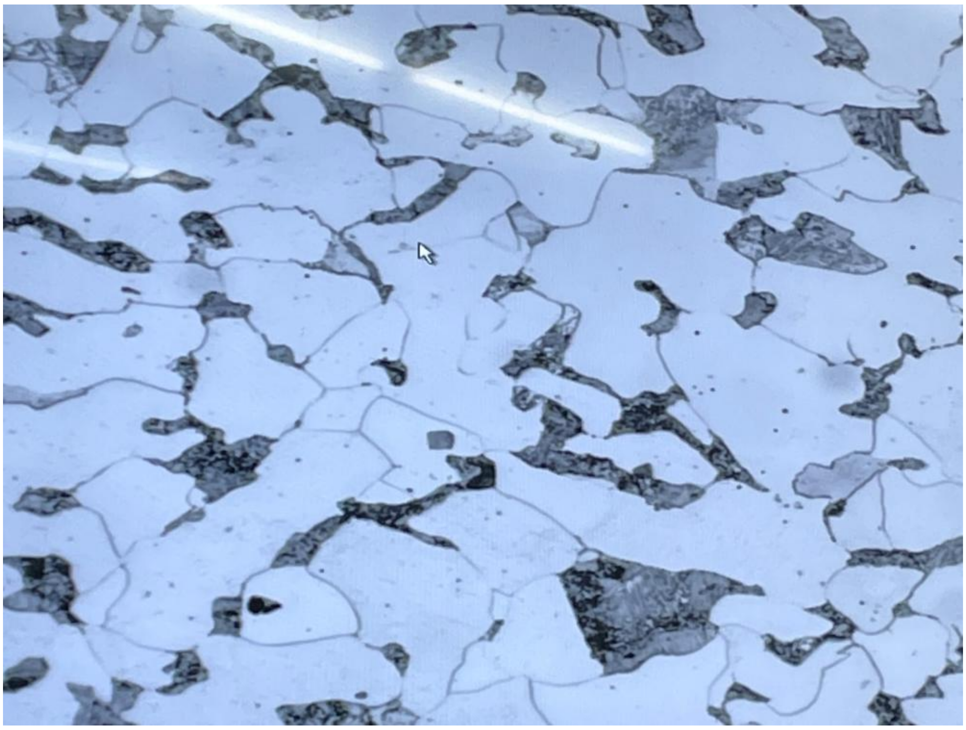

Figure 1: Micrograph of the as-received EN3 (1015) specimen

Figure 1 shows the microstructure of the as-received EN3 specimen. The structure consisted of light, equiaxed ferrite grains, with dark pearlite present in a smaller proportion and distributed mainly along the ferrite grain boundaries. This relatively low proportion of the harder pearlite phase is consistent with the low hardness of 45.67 HRA measured for this specimen.

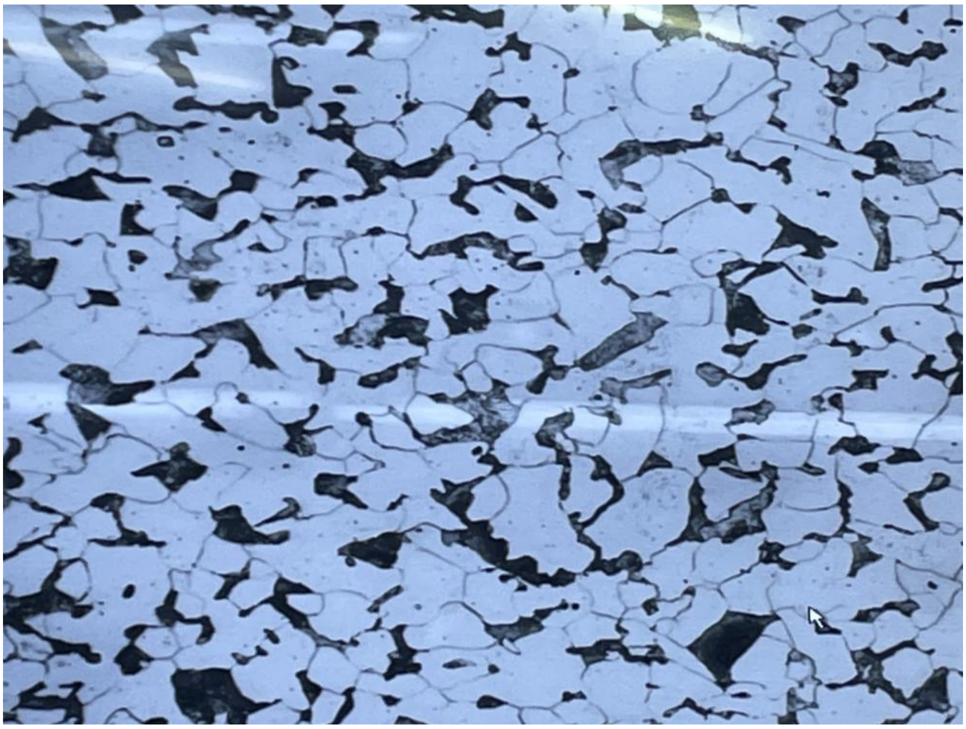

Figure 2: Micrograph of the work hardened EN3 (1015) specimen

Figure 2 shows the microstructure of the plastically deformed (work hardened) EN3 specimen. As in the as-received EN3 specimen, the structure consisted predominantly of ferrite with a smaller fraction of pearlite. However, the grain structure appeared visibly distorted relative to the as-received specimen, which is consistent with the cold work applied to this specimen. This deformed grain structure, together with the associated increase in dislocation density, accounts for the higher hardness of 58.33 HRA recorded for this specimen compared with the as-received EN3 specimen.

Figure 3: Micrograph of the EN8 (1040) specimen, magnification 50×

Figure 3 shows the microstructure of the EN8 specimen. In comparison with both EN3 specimens, the proportion of the dark pearlite phase was markedly greater, occupying close to half of the observed area, while the remaining light regions corresponded to proeutectoid ferrite. This is consistent with the higher carbon content of EN8 (0.4% C) compared with EN3 (0.15% C), and correlates with the highest average hardness of 65.67 HRA recorded among the three specimens.

4. Interpretation and Discussion of Results

The results obtained in this practical demonstrated a clear relationship between the microstructure of a steel and its measured hardness. The as-received EN3 (1015) specimen, being a low carbon steel, contained predominantly soft ferrite with only a small fraction of the harder pearlite phase, which corresponded to the lowest average hardness of 45.67 HRA recorded among the three specimens.

The work hardened EN3 specimen, although chemically identical to the as-received EN3 specimen, recorded a considerably higher average hardness of 58.33 HRA. This increase could not be attributed to a change in phase composition, since both specimens had the same carbon content, but rather to the effect of plastic deformation on the grain structure. Cold working increases the density of dislocations within the crystal lattice, and the resulting increase in dislocation interactions impedes further dislocation motion. This strain hardening mechanism increased the resistance of the material to further plastic deformation, and was observed microscopically as a distorted, elongated grain structure relative to the undeformed specimen.

The EN8 (1040) specimen recorded the highest average hardness of 65.67 HRA of the three specimens tested. This was attributed to its higher carbon content of 0.4%, which resulted in a substantially greater proportion of pearlite in the microstructure, as observed in Figure 3. Since pearlite is a harder and stronger microconstituent than ferrite, an increase in the volume fraction of pearlite directly increased the bulk hardness of the steel.

Overall, the results confirmed that the hardness of the steel specimens increased in the order: as-received EN3 < work hardened EN3 < EN8, and that this trend could be explained in terms of the microstructural mechanisms of solid solution/second-phase strengthening (increasing pearlite content with carbon content) and strain hardening (increased dislocation density due to cold work).

It is noted that the practical brief lists the EN3 (1015) specimen as containing 0.15% carbon, and this value has been used consistently throughout this report.

4.1 Advantages and Disadvantages of Work Hardening

Both strengthening mechanisms observed in this practical, namely strain hardening and an increase in carbon content, offer certain benefits but also carry associated drawbacks, as summarised in Tables 3 and 4 [2].

Table 3: Advantages and disadvantages of work hardening (cold work) [3]

Advantages	Disadvantages
Increases yield strength and hardness without any change in alloy composition or heat treatment	Significantly reduces ductility, so the material may fracture with little warning under further deformation

Advantages	Disadvantages
Simple and inexpensive to achieve, requiring only plastic deformation (e.g. rolling, drawing, forging) at room temperature	Reduces toughness and impact resistance, making the material more brittle
Improves the wear resistance of the deformed surface	Introduces internal (residual) stresses, which can cause distortion, cracking, or promote stress-corrosion cracking
Can improve fatigue strength in some cases, due to compressive residual stresses introduced at the surface	The strengthening effect is removed by subsequent annealing/recrystallization, so properties are lost if the part is later exposed to elevated temperature (e.g. welding)
	Non-uniform deformation can result in non-uniform properties through the section

4.2 Advantages and Disadvantages of Increasing Carbon Content

Table 4: Advantages and disadvantages of increasing the carbon content of steel [4]

Advantages	Disadvantages
Increases hardness and tensile strength, due to the greater proportion of pearlite (and eventually cementite) formed	Reduces ductility and toughness, making the steel more brittle
Improves wear resistance	Reduces weldability, increasing the risk of cracking in the heat-affected zone during welding
Allows the steel to respond better to heat treatment, since higher carbon content permits more martensite to form on quenching	Reduces machinability over certain carbon ranges
Well suited to applications such as cutting tools, gears and springs, which demand high strength and wear resistance	Increases the risk of quench cracking during heat treatment due to the greater volume change associated with martensite formation
	Generally increases cost and reduces formability, making the steel more difficult to cold-work or bend

Both mechanisms therefore represent a trade-off between strength/hardness and ductility/toughness. Work hardening achieves this trade-off mechanically and reversibly, since the effect can be removed by annealing, whereas increasing the carbon content achieves it compositionally and is essentially permanent unless the carbon content itself is subsequently altered, for example by decarburization. This trade-off was reflected in the present results, where the hardest specimen (EN8) relied on a higher carbon content, while the intermediate hardness of the work hardened EN3 specimen was achieved without any change in composition, purely through plastic deformation.

References

[1] "Practical 2: Microscopic Examination," Practical Study Guide, Dept. of Mechanical Engineering Science, Univ. of Johannesburg, Johannesburg, South Africa.

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