Laboratory Exercise 1

Hardness Mapping

MEC-E6007 - Mechanical Testing of Materials D

Aalto University

Group Members

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Contents

1. Introduction and Background:

The field of engineering, especially in transportation, is facing new obstacles due to environmental changes and the need for global sustainability [1]. Take the maritime industry, for example. To make ships more sustainable, engineers are exploring the use of high-strength steels in building large, welded structures [2]. By incorporating innovative structural designs, such as new arrangements and shapes, engineers can significantly decrease the weight of cruise ships [3].

However, using stronger materials comes with its own set of challenges. High-strength steels are particularly sensitive to how they are made, and defects can arise during the manufacturing process. This means that processes like cutting and welding must be fine-tuned to ensure that the full-strength potential of these materials is utilized.

To tackle this issue, it's crucial to delve into the intricacies of how the material's strength properties change throughout the manufacturing process. This involves a deep understanding of the microstructural characteristics of the material, which can shed light on why these changes occur. By grasping these underlying mechanisms, engineers can optimize manufacturing processes to enhance the strength and durability of transportation structures while meeting sustainability goals.

2. Methods:

Different methods are used for checking hardness of materials. The three most common methods are brinell test, vickers test and rockwell test.

The first widely used standardized hardness test, the Brinell method determines the indentation hardness of metal materials and is typically used for materials with a coarse surface or a surface too rough to be tested through other methods. The Brinell test is not useful for fully hardened steel or other hard materials, however, and often leaves a large impression on the metal. Developed to provide a less destructive alternative to the Brinell test, this differential-depth method eliminates the errors associated with mechanical imperfections. Quicker and cheaper than the Brinell and Vickers tests, the Rockwell test requires no material prep, and hardness value is easily readable without any extra equipment, making this one of the most commonly used methods of measuring metal hardness. Making use of a diamond indenter, the Vickers hardness test is done with less force and more accuracy than the Brinell test. By magnifying the surface of a metal, this test can target specific microstructural constituents like martensite or bainite, or assess the quality of heat treating or surface hardening operations. Requiring an optical system and material prep, the Vickers test incurs higher costs and takes longer to complete than the Rockwell test [4].

For this report, we have used Vickers hardness test for calculating the hardness of the specimen that was provided. Duramin 40 AC2 hardness tester was used. According to the product website, Duramin-40 is the primary range of Struers micro/macrohardness testers. It is available with a manual and motorized XY-stage and with an overview camera. Duramin-40 comes with three load ranges; 10.0 gf – 10.0 kgf, 10.0 gf – 31.25 kgf, and 1.0 gf – 62.5 kgf. The tester includes an integrated PC with a separate monitor for touchscreen or mouse operation. Dual monitors are also an option. The test cycle is fully automatic, and a motorized six-position turret is standard. Add-on modules include Kc fracture measurements, mapping, and weld measurements [5].

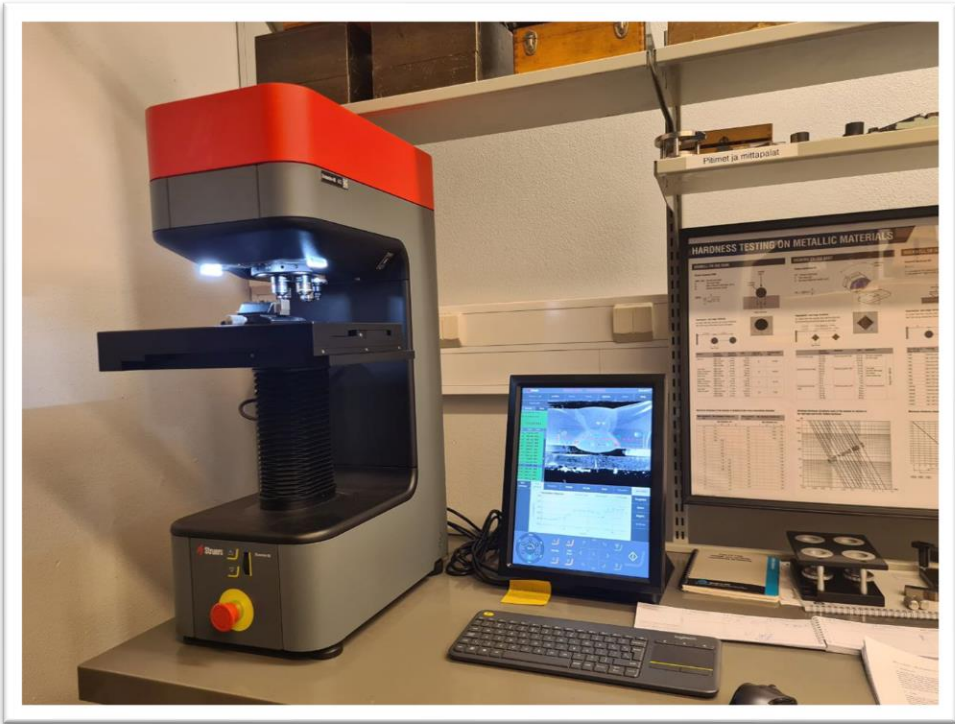

Figure 1: Duramin 40 AC2 Testing Apparatus.

The specimen used is a weld between two different metals with different hardness levels. The apparatus used made 18 indents on the specimen. Four measurements were taken in a group of 5 measurements. 4 indents each were made on both the metals surfaces, then 4 indents each were made in the regions between the weld and the metal, and 4 more indents were made on the weld. A load of 10 kgf was applied. A diamond shaped indent was made, and its measurements were made using the apparatus camera. The correlation between the load applied and the dimensions of the indent help to calculate the hardness of the material.

Figure 2: Indent setup for specimen.

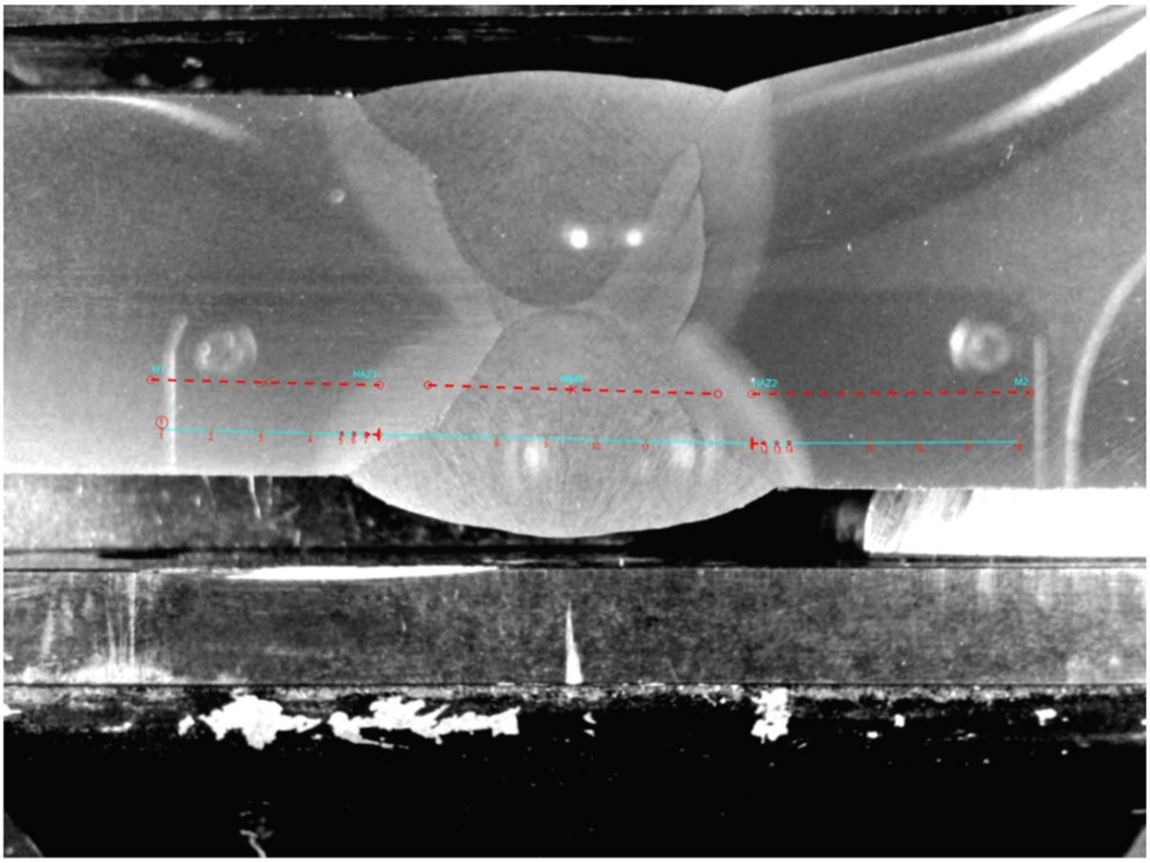

Figure 3: Specimen image captured from Duramin-40 AC2 camera.

3. Results:

Results from 18 indents were obtained.

ID	1 (1/1)
Hardness	193.03 HV1
d1	0.2955 mm
d2	0.3063 mm
position	x: 94.28 mm y: 53.87 mm
Conversions	
Time	3:22:37 PM

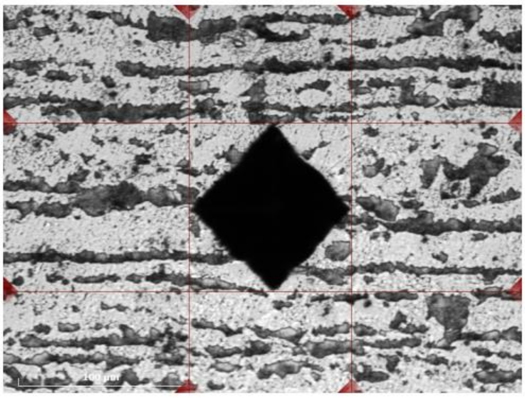

Figure 4: Images and results from Duramin 40 AC2, Metal 1.

ID	5 (1/1)
Hardness	205.4 HV1
d1	0.2886 mm
d2	0.2948 mm
position	x: 101.54 mm y: 53.70 mm
Conversions	
Time	3:23:13 PM

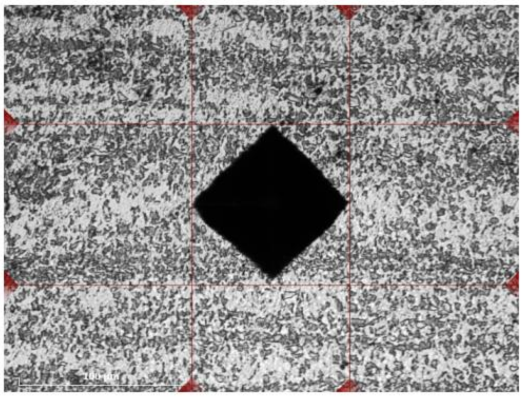

Figure 5: Images and results from Duramin 40 AC2, area between Metal 1 and Weld.

ID	9 (1/1)
Hardness	262.91 HV1
d1	0.2625 mm
d2	0.2532 mm
position	x: 109.82 mm y: 53.52 mm
Conversions	
Time	3:23:50 PM

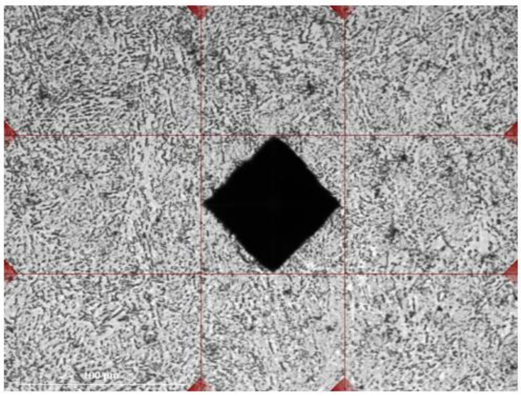

Figure 6: Images and results from Duramin 40 AC2, Weld.

ID	**13 (1/1)**
Hardness	256.79 HV1
d1	0.2609 mm
d2	0.2609 mm
position	x: 119.11 mm y: 53.31 mm
Conversions	
Time	3:24:26 PM

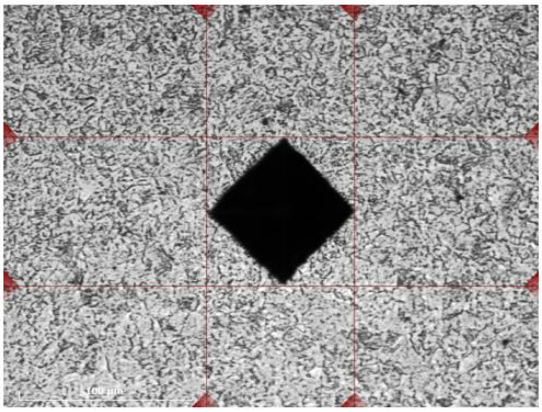

Figure 7: Images and results from Duramin 40 AC2,a rea between Weld and Metal 2.

ID	**16 (1/1)**
Hardness	292.71 HV1
d1	0.2417 mm
d2	0.2470 mm
position	x: 124.89 mm y: 53.35 mm
Conversions	
Time	3:24:53 PM

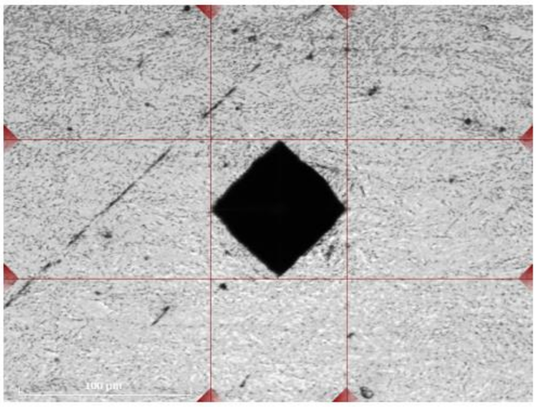

Figure 8: Images and results from Duramin 40 AC2, Metal 2

The following table contains hardness values from all the indents that were made.

Table 1: Hardness Measurements

Area	Measurement Index	Result HV1
Metal 1	1	193.03
	2	191.96
	3	189.1
	4	193.52
HAZ Between metal 1 and weld	5	205.4
	6	207.63
	7	236.75
Weld	8	259.85

	9	262.91
	10	264.51
	11	262.16
HAZ Between weld and metal 2	12	259.84
	13	256.79
	14	230.9
Metal 2	15	289.99
	16	292.71
	17	287.29
	18	292.73

Pattern	Mean	Min	Max	SD	Range	USL	LSL	Cp	Cpk
1	243.17	189.10	292.73	37.89	103.63	0	0	0	-2.14

4. Discussion:

The hardness values for Metal 1 range from 189.1 to 193.52 HV1. These values indicate a relatively consistent level of hardness within this region, with slight fluctuations but no significant deviation. In the area between metal 1 and the weld, the hardness increases, with values ranging from 205.4 to 236.75 HV1. This increase in hardness is because of the presence of the weld, which often alters the microstructure of the material and may introduce changes in hardness.

The weld exhibits the highest hardness values among all regions tested, ranging from 259.85 to 264.51 HV1. This is expected as welding typically results in a localized increase in hardness due to the rapid heating and cooling cycles involved in the process, leading to the formation of a distinct microstructure.

In the area between the weld and metal 2, the hardness decreases significantly in this region compared to the weld, with values ranging from 230.9 to 259.84 HV1. This decrease in hardness could be attributed to factors such as heat-affected zone effects or differences in material composition between the weld and Metal 2. Similar to Metal 1, Metal 2 exhibits relatively consistent hardness values ranging from 287.29 to 292.73 HV1. These values suggest that the hardness of Metal 2 is comparable to or slightly higher than that of Metal 1.

4.1. Comparison:

The following table represents the values of calculated hardness by our apparatus and the benchmark values according to literature.

Table 2: Comparison of Hardness Values

Material	Our lab Test	Reference	Ref. No.	Predicted Metal
Metal 1	189.1 to 193.52	150-190	[6]	S355 Grade
Metal 2	205.4 to 236.75	210-266	[7]	S690 Grade

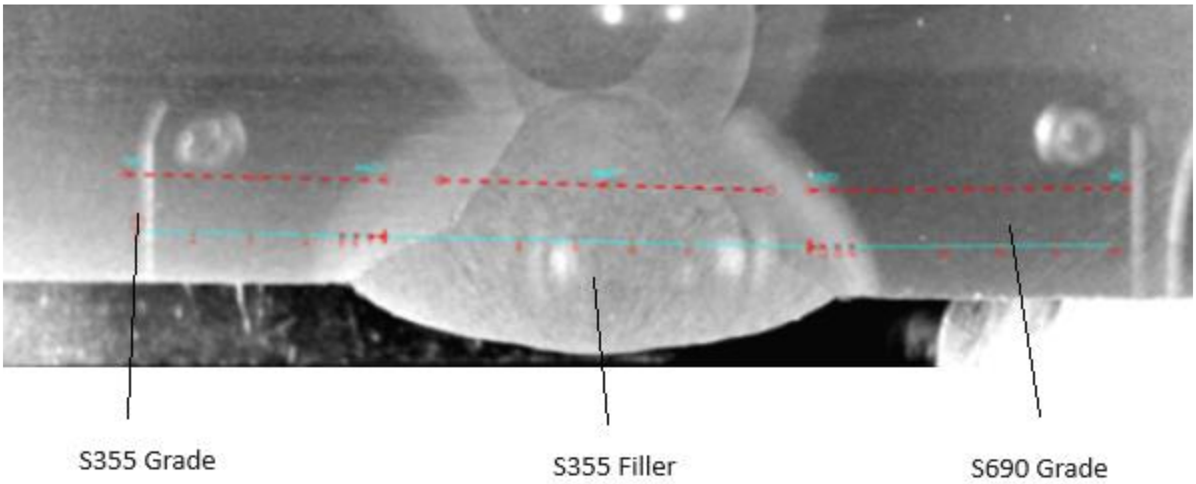

Figure 9: Identification of Materials

As, according to above analysis, it is very clear that on the left side of weld S355 material is there and on the right side it is S690. There are many ways to identify the materials, the basic one is using hardness measurements.

Possible Weak Zones:

There are many places where the welded joint can be weak. Following are some of them.

1. **Heat-Affected Zone (HAZ) Boundaries:**

The boundaries between the HAZ of the S355 steel and the S690 steel are critical to weaknesses due to the abrupt changes in material properties caused by the welding process. These boundaries may experience variations in hardness, microstructure, and residual stresses, making them prone to cracking or deformation.

2. **Fusion Zone:**

The fusion zone, where the filler metal has melted and fused with the base metals, can be a critical location for weaknesses. The varying compositions and mechanical properties of the S355 and S690 steels can result in metallurgical incompatibilities, leading to potential defects such as lack of fusion, incomplete penetration, or brittle microstructures.

3. **Welded Zone:**

Improper welding process may lead to development of defects inside the weld. Moreover, if the weld is not according to standards, the material will not be able to develop the proper strength between two base materials ultimately leading to weaknesses.

Reasons for Possible Weaknesses:

1. **Material Mismatch:**

Differences in strength and composition between S355 and S690 steels create weak points at their interfaces.

2. **Metallurgical Incompatibility:**

During welding, these differences lead to microstructural changes and the formation of brittle phases, weakening the joint.

3. **Stress Concentration:**

Abrupt changes in material properties create stress concentration points prone to crack initiation and propagation.

4. **Welding Process Parameters:**

Improper settings can lead to defects like lack of fusion or excessive hardness in the heat-affected zone, compromising joint integrity.

5. **Welding Technique and Quality:**

Inadequate techniques or insufficient cleanliness may result in poor fusion, porosity, or other defects weakening the joint.

4. Conclusions:

The variations in hardness across different regions of the sample could have implications for its mechanical properties and performance in service. For example, the higher hardness of the weld indicates greater resistance to wear and deformation in this area, which may be desirable depending on the application. However, it's essential to consider other factors such as ductility, toughness, and corrosion resistance in addition to hardness when assessing the overall suitability of the material for its intended use.

In conclusion, the Vickers hardness test results provide valuable insights into the distribution of hardness across different regions of the sample, highlighting variations that may influence its mechanical behavior and performance. Further analysis and consideration of other relevant factors are necessary to fully understand the implications of these findings.

5. References:

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