MEC-E6007 – Mechanical Testing of Materials

LABORATORY EXERCISE 1 – HARDNESS MEASUREMENT

Report

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OBJECTIVE

Determine the base material type on each side of the weld and determine possibly locations of weakness within the welded joint.

BASIC INFORMATION

- Testing Method: Vickers
- Materials: S690 and S355
- Welding method: submerged arc welding (SAW)
- Hardness scale: HV1
- Dwell time: 10 sec
- Standard Hardness tester (DURAMIN-40-AC2)
- Indenter (Diamond Tip)

INTRODUCTION

Various standardized tests are available to assess the hardness of materials, including Rockwell Hardness Testing, Vickers Hardness Testing, and Brinell Hardness Testing. In this case, we employed the Vickers Test to determine the hardness of the provided sample. The Vickers test utilizes a 136° pyramidal diamond indenter that creates a square-shaped indentation. A load is applied for a duration of 10-15 seconds [1]. The experimental setup utilized the Struers Duramin-40-AC2 testing machine, which features multiple magnification lenses and an indenter mechanism that allows for interchangeable indenters based on the specific test being conducted [2].

THEORY

The Vickers Pyramid Number can be calculated the following way [1]:

$$HV = 1.854 \cdot \left(\frac{F}{D^2}\right)$$

The applied force (F) is measured in kilogram-force, and the area of indentation (D^2) is measured in square millimeters. It is crucial to ensure that the diagonals of the indentation are of similar lengths during the test to avoid any potential errors.

HARDNESS MEASUREMENT AND VICKERS HARDNESS

In the first exercise, the goal is to study how welding has influenced the mechanical properties of the welded connection extracted from a real-world structure. For this, two pieces of welded steel of different material grades were examined using the Vickers method to characterize the hardness and associated properties of the weldment and the adjacent base materials.

This testing method is a widely used method for determining and evaluating the hardness of materials based on the indentation hardness. It is particularly suitable for the examination of metals and is often used to assess material strength as well as its homogeneity.

The experimental setup involved the testing of two welded steel pieces, with the materials used being types S690 and S355 grade. For the welding, the submerged arc welding (SAW) method was used. The specimen was already carefully prepared, including cleaning, grinding, and polishing to ensure reliable testing results.

To gain a complete understanding of the different zones within the specimen, 20 measure points in total were applied and set, which are shown in Figure 2 and Figure 3. The measurements were carried out approximately in the middle of the test piece, taking into account the minimum distances and different zones specified in the standard SFS-EN ISO 9015-2 [3].

As shown in the figures, there are at least three measurement points in each section, as instructed in the standards manual, ensuring the obtention of high-quality results. In the right heat-affected zone, 8 different points were set due to a change within this region.

Figure 1: prepared specimen

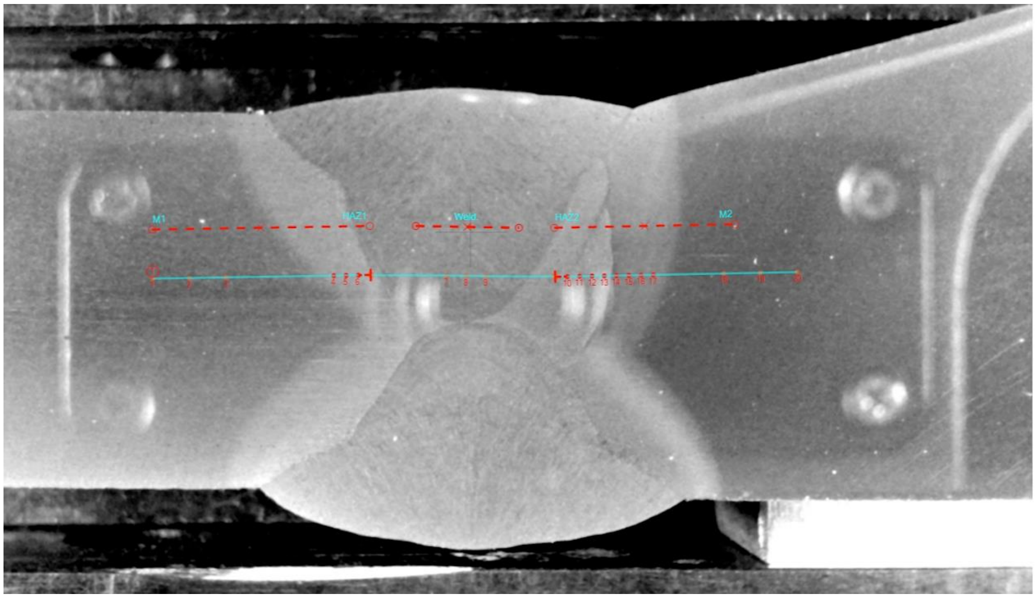

Figure 2: Snapshot of the specimen and the set measurement points

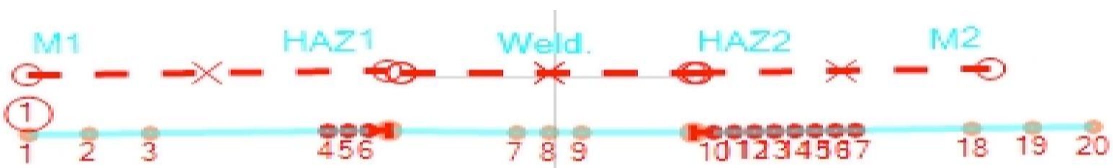

Figure 3: detailed overview of the set points within the different zones

During the testing process, a pyramidal diamond indenter with an angle is used to create an indentation in the material. The test load was applied consistently at HV1, and the dwell time was set at 10 seconds as given in the task. The resulting impression size, measuring the diagonal length, was then automatically measured using a microscope and calculating the Vickers hardness. Individual points could be adjusted manually afterwards if the measuring points were not exactly in the corners of the print.

Figure 4: Struers Duramin-40 AC2 testing apparatus

PRECAUTIONS

- Ensure that the sample is flat.
- The surface of the sample should be perpendicular to the indenter.
- Avoid any disturbances and maintain distance from the specimen.
- Select the force carefully, considering the material type.
- In the case of nonhomogeneous materials, the load value can impact the length of the diagonal. If the force applied is too low, the diagonals may not be comparable.

RESULTS AND INTERPRETATION

The resulting measurement forces can be found in Figure 5 and Figure 6. Pay attention that the graphic in Figure 5 starts counting from 0 to 19 whereas the points in Figure 6 are listed from 1 to 20 as marked in the previous two figures!

As you can see in Figure 5, points 0 to 2 have a lower hardness than the tested steel on the right (points 17 to 19). This indicates that the steel on the left side is from grade S355 and the right one from S690. Points 3 to 5 were set in the left heat-affected zone. While the first two show a similar, just a bit higher hardness than the left specimen, the result of point 5 is much higher than expected.

Points 6 to 8 are located in the weld and have quite similar values as the tested steel on the left side so there is no difference or loose of quality between both sections.

Measurements 9 to 16 are set in the right heat-affected zone. As you can see, the hardness of the welded specimen slowly increases with increasing distance from the weld seam due to the higher grade of the right used steel. There is also a sudden rash in the results at point 13, which is exactly in the transition between the two different heat-affected zones. So, there should be a higher hardness due to this change of properties. The other three points 14 to 16 in the right heat-affected zone indicate a higher hardness than the left ones due to proximity to the higher-grade steel on the right side.

After getting the calculated and measured forces, point 16 was checked and adjusted manually due to much lower values than the surrounding measurements. Even though the corners of the print were set correctly, the results are still much lower than the other ones.

The lowest values were measured at point 7 (185.36 HV1) in the middle of the welding and the highest hardness was measured at point 18 (288.15 HV1) in the right steel specimen of grade S690. The mean hardness of the whole specimen is 220.11 HV1.

As you can observe, the hardness of the specimen differs a lot depending on the zones you look at. The welding and the heat-affected zones on the left side show quite similar values to the lower grade steel of S355 quality, whereas the values on the right side of the welding are higher and get closer to the higher quality steel. But in total, the welding and the heat-affected zones show lower hardness than the parent material.

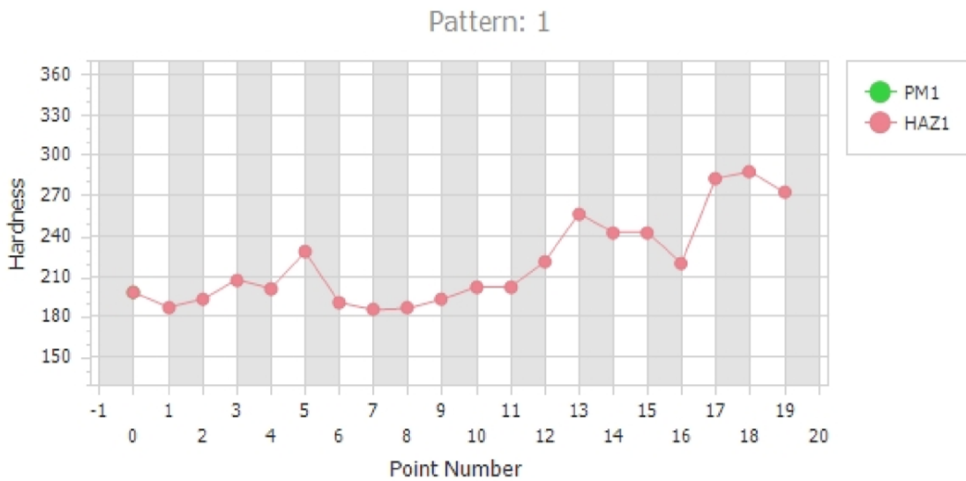

Figure 5: results of the measured hardness [HV1]

Pattern: 1

Measurement Index	Result
1 (1/1)	198.06 HV1
2 (1/1)	187.24 HV1
3 (1/1)	193.02 HV1
4 (1/1)	207.63 HV1
5 (1/1)	201.17 HV1
6 (1/1)	228.32 HV1
7 (1/1)	190.56 HV1
8 (1/1)	185.36 HV1
9 (1/1)	186.3 HV1
10 (1/1)	192.98 HV1
11 (1/1)	202.21 HV1
12 (1/1)	202.23 HV1
13 (1/1)	220.9 HV1
14 (1/1)	256.78 HV1
15 (1/1)	242.98 HV1
16 (1/1)	242.94 HV1
17 (1/1)	219.95 HV1
18 (1/1)	282.85 HV1
19 (1/1)	288.15 HV1
20 (1/1)	272.63 HV1

Pattern	Mean	Min	Max	SD	Range	USL	LSL	Cp	Cpk
1	220.11	185.36	288.15	33.40	102.79	0.00	0.00	0.00	-2.20

Figure 6: detailed results of the measured hardness

SOURCES OF POTENTIAL WEAKNESSES

Welded joints inevitably have varying points of weakness depending on the welding process and materials used.

Heat Affected Zone (HAZ)

The intense heat during the welding process leads to changes in the material's microstructure and influences the mechanical properties. An example of this is seen with point 5, where the welded material caused the material to harden in that region. This is a hardness test so only that property was tested, but the HAZ may also experience changes in ductility and toughness.

Weld Metal

The weld metal deposited during the welding process which has fused with the respective base metals creates an area known as the fusion zone. This is an area of potential weakness due to the variation of hardness and ductility at the interface between the base metals and weld metal.

Welding Process

Improper preparation of the joints or inadequate welding technique are unknown parameters for us to consider as our group did not carry out the welding procedure. Welding defects may contribute to potential weakness in the joint. Examples include porosity in the fusion zone, incomplete fusion, or cracks which all impact the resulting hardness of the zone.

CONCLUSION

The points of testing on the base metals (1-3 and 18-20) clearly indicate the relatively homogenous hardness properties of the two separate metals being examined. The first heat affected zone featured an unexpected outlier at point 5, showing the variability of mechanical properties from the welding procedure.

Overall, the areas impacted by the welding process yielded lower hardness scores, and the graph visibly demonstrates the weakness of the respective regions compared to the two parent metals. Although the experiment didn’t fully follow the SFS-EN ISO 9015-2 standards, it followed them as loose guidelines, particularly noting the recommended amount of test points per region. As a result, it's confident to say that this test would be close enough to a similar test being carried out in an industrial setting.

This experiment effectively demonstrates the impact welding has on mechanical properties of the two materials and portrays the drop in hardness in the area affected by the process of welding.

REFERENCES

[1] P. Moore and G. Booth, "Mechanical testing of welds," *The Welding Engineeing Guide to Fracture and Fatigue,* pp. 113-141, 2015.

[2] Struers, "DURAMIN-40," [Online]. Available: https://www.struers.com/en/Products/Hardness-testing/Hardness-testing-equipment/Duramin-40#. [Accessed 20 3 2024].

[3] SFS, *SFS-EN ISO 9015-2: Destructive tests on welds in metallic materials. Hardness testing. Part 2: Microhardness testing of welded joints,* 2016.