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# Experience with high-frequency mechanical impact method for weldments of sheets of different thicknesses

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**Abstract**

The interim results of two projects of the Technology Agency of the Czech Republic are presented, the subject of which is the verification of the potential of the industrial use of the high-frequency mechanical impact (HFMI) method for increasing the load-bearing capacity and fatigue of the material. The fatigue life of welds of steel sheets of various thicknesses and in a wide range of strengths of welded steels for the construction of rolling stock and steel bridges are experimentally verified.

The authors have already presented partial results, Kepka jr. et al. (2022). The new results are based on a larger number of test samples. First findings on the application of the HFMI method to thin (4 mm) and very thick (90 mm) sheet welds are included. The results are compared with the general recommendation of the International Institute of Welding (2016).

Partial attention was also paid to the endurance of compressive stresses introduced into the weld area by the application of HFMI. The fatigue tests were completed by measuring residual stresses by X-ray diffraction on selected test specimens with the application of HFMI before and after the completion of 10 million loading cycles.



*Keywords:* HFMI; welded joint; fatigue resistance; fatigue life; residual stresses

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## Introduction

The fatigue life is divided into the initiation phase and the crack propagation phase. In the presence of sharp notches, such as in welds, the fatigue life is dominated by the crack propagation phase. The fatigue life of welds of ordinary structural steels without additional modifications depends to the highest extent on the quality and geometry of the weld. Evaluation of the quality of the weld is an important factor for the accurate determination of the fatigue life of the weld joint. When using common filler welding materials, tensile residual stresses are present in the transition area of the weld to the base material, which can reach the yield point of the softer of materials used (filler/ parent material). These stresses help the initiation of a fatigue crack and thus significantly shorten the fatigue life of a given welded joint.

The HFMI method is a highly progressive and user-friendly approach to increasing the fatigue life of welded steel structures. It is suitable for common types of steel, but its advantages are most pronounced in high-strength steel welds. High-frequency mechanical impact improves weld geometry because it smoothens the transition and increases smoothness. It also eliminates microcracks from welding. The last but not least effect is that it induces compressive residual stresses. Due to the scope, this text does not address microstructure and surface properties changes. These effects are included in the resulting S-N curves.

For loading with constant amplitude, this improvement is defined by Marquis and Barsoum (2016) in the IIW recommendation. According to this recommendation, there will be an increase in the contractual fatigue strength and a shift of the fatigue S-N line towards higher durability (higher FAT class).

The application of HFMI is expected to improve fatigue strength, especially for steels with high yield strength. For a thickness of 15 mm, there is an expected result given by the recommendation of the International Institute of Welding. HFMI will improve one additional FAT class for every 200 MPa increase in yield strength, as shown in the figure taken from the IIW recommendation. No results were found in the literature for non-standard thicknesses.

In the following chapters, the results of tests for plates with thicknesses of “standard” 15 mm, 4 mm, and 90 mm are presented.

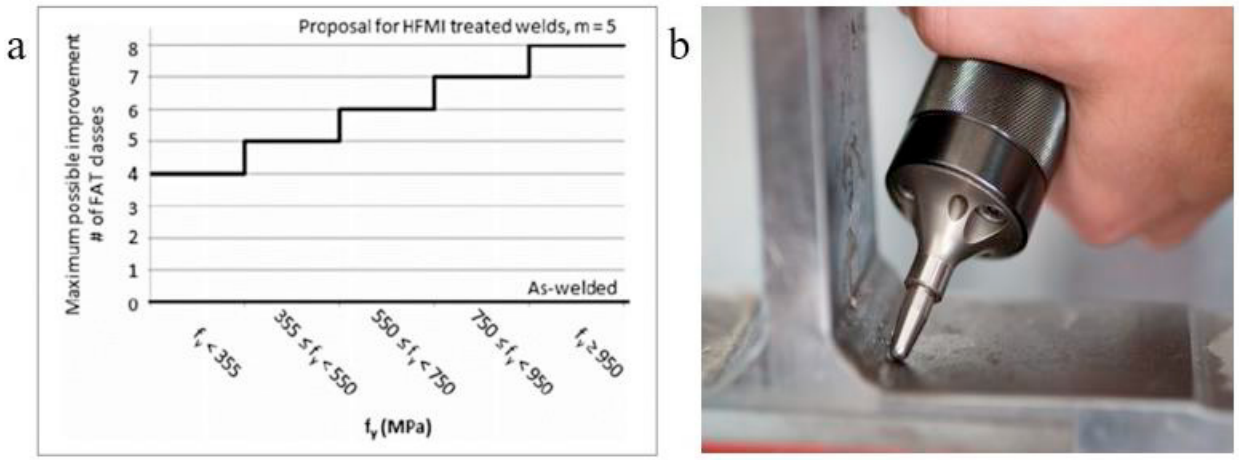


Fig. 1. (a) The potential HFMI improvement; (b) An application of the HFMI method.

## 1. Thick sheet welds (90 mm)

A typical sample in Fig. 2 was selected to determine the efficiency of HFMI technology on materials of larger thicknesses, pin with diameter 5 mm was used for the application of HFMI. Set consists of 6 samples with dimensions of 700 x 100 x 90 mm with a butt V weld on a ceramic backing. The samples thus designed may represent a common structural detail of steel bridges or a major structural element. Structural steel S355NL was used as the base material. The V-weld was carried out on a ceramic backing by methods 135 (root of weld) and 121 (filling runs + capping run). Additional material was used by G3Si1 (135) and M-12+S-717 (121). Preheat of 80-120°C was used for welding, and the interpass temperature did not exceed 225°C. All samples were tested by NDT tests (VT, MT, UT) to detect possible microcracks after welding, no cracks were detected. After quality verification, the samples were divided into 2 groups. The first group of samples was processed by HFMI. The second group remained as welded as a normal structural joint without further machining.

The samples were tested by a four-point bending at stress ratio R = 0.1. The testing was carried out on an electro-hydraulic loading machine FU-O-250. Stand for a 4-point bend was used on the machine.

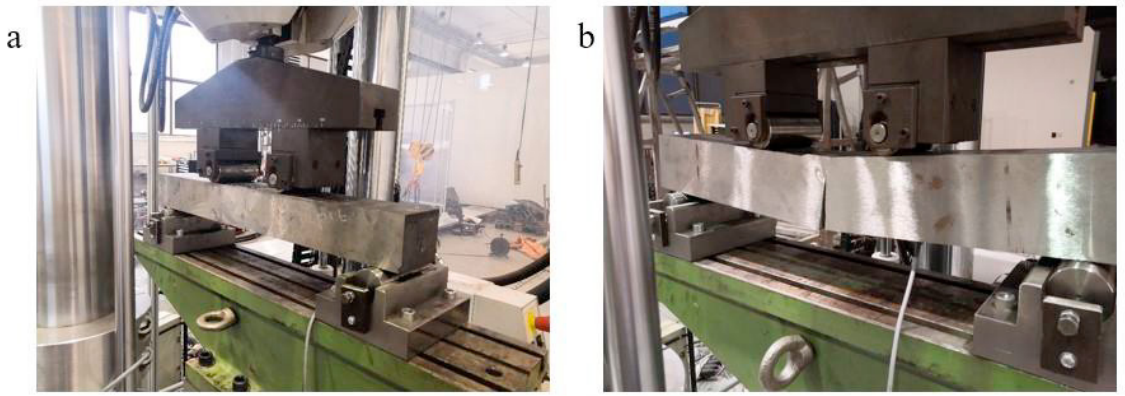


Fig. 2. (a) The testing sample in machine FU-O-250; (b) The characteristic crack of the sample.

The progress of the tests was monitored by a pair of strain gauges attached to the root of the weld. The samples were cycled to a specified number of cycles at a constant stress range. The end of the test criterion was reaching the limit number of cycles or breaking the sample. The fatigue test results obtained are shown in Table 1.

Table 1. Loading level and number of cycles to failure, four-point bending test, R = 0.1

| the sample number | Stress range [MPa] | AS WELDED | HFMI |
|---|---|---|---|
| | | number of cycles to failure | number of cycles to failure |
| 1 | 130 | 663 068 | 2 280 417 |
| 2 | 130 | 507 655 | 2 174 608 |
| 3 | 130 | 601 156 | 1 803 951 |

## 2. Thin sheet welds (4 mm)

The thin sheet metal samples were made of 1.4162 stainless steel. The samples were manufactured according to the drawing in Fig.3. The thickness of the chosen steel for testing was 4 mm. A V-weld with a permanent backing welded by method 135 was chosen to produce the sample. HFMI device with pin with diameter 5 mm was used.

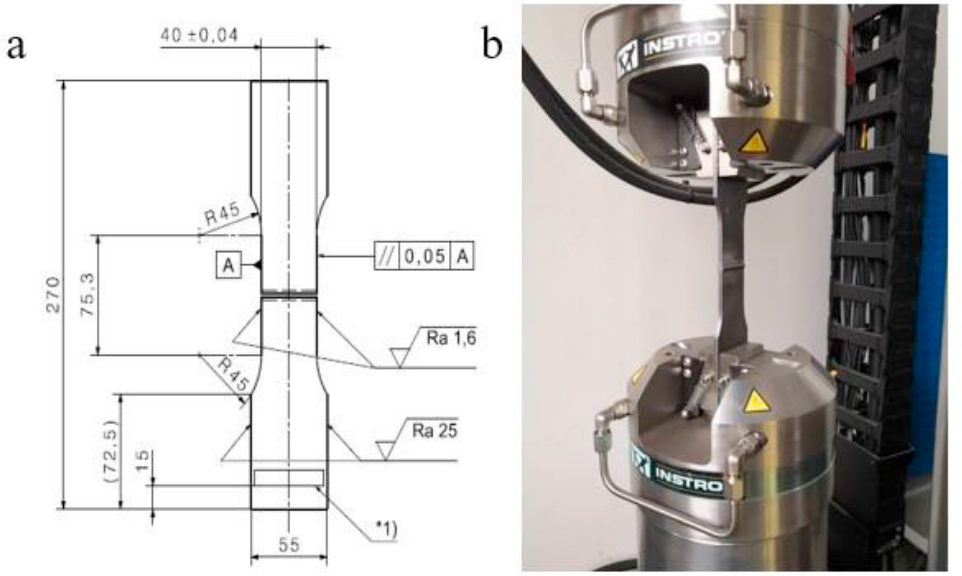


Fig. 3. (a) The thin test sample drawing; (b) The sample during the test.

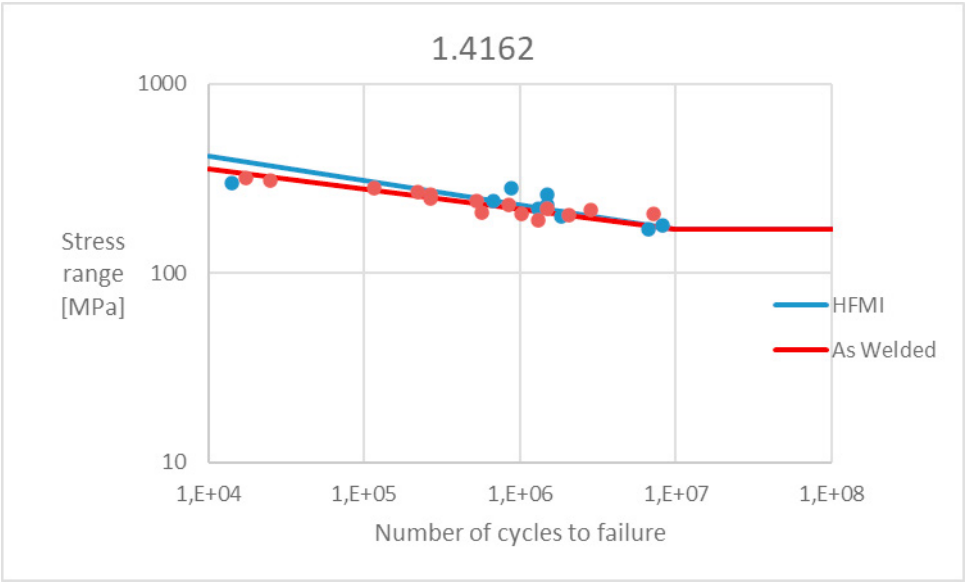


Fig. 4. The mean SN lines for R = 0, stainless steel 1.4162 of thickness 4 mm.

The samples were loaded with stress ratio R = 0. The mean SN line was evaluated and the graph was plotted with the so-called fatigue limit in 10 million cycles, Fig 4. SN lines do not differ from each other. According to this test results, it is not possible to use the HFMI method for sheets of thickness 4 mm using the standard HFMI postprocessing configurations for sheets of thickness > 5 mm with high weld angle. In further research, the focus will be on changing the pressure force and pin size.

## 3. T-welds (15 mm)

The fatigue test samples of T-welds were prepared from two materials. The first was a 15 mm thick sheet steel S235JR. The S235JR steel was chosen for the tests as a commonly used structural steel. In this case, the application of HFMI should have little benefit. The second test material was chosen as a 15 mm thick high-strength steel S460MC. This should already show a greater benefit of the HFMI method. The additional G3 Si1 material was used for the S235JR steel test samples. The additional G46 4 M21 4Si1 material was chosen for the S460MC steel samples. The pin of diameter 3 mm was used. A hydraulic cylinder AH-25-100-M06 was used to load the samples. The sample clamped in the test stand is shown in Fig. 55. A deformation of the sample in the direction of loading was taken as the failure criterion for completion of the fatigue tests. If the test was terminated because of achieving this criterion, a penetration test was carried out for confirmation of the crack. The cracks found ran along the weld at the upper edge of its transition into the material.

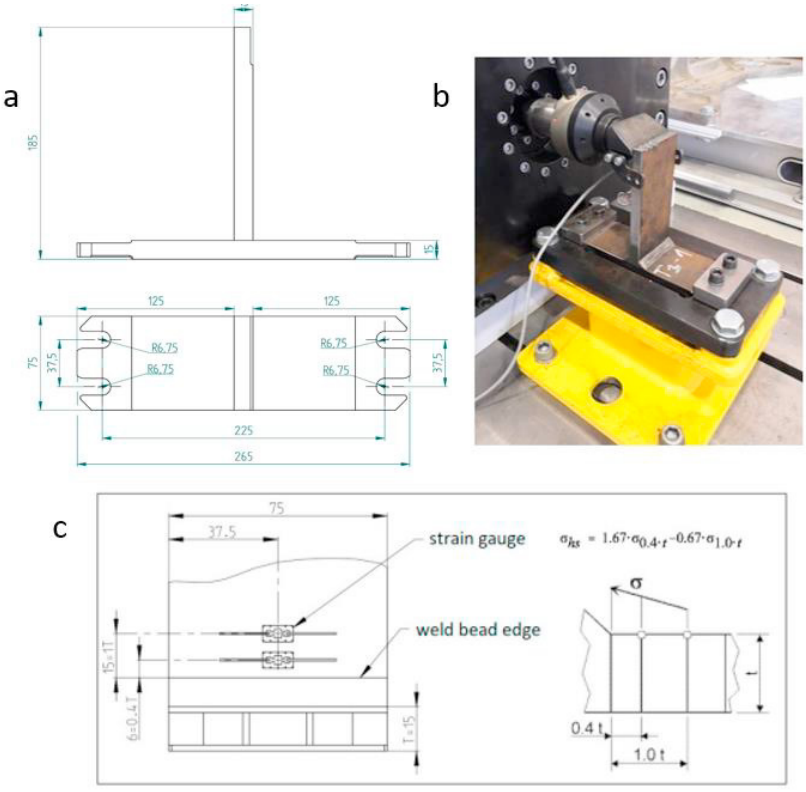


Fig. 5. (a) T-weld test sample; (b) T-weld testing sample during the test, (c) hot-spot stress measurement.

The test was controlled by force and hot-spot structural stresses were measured. The stress ration was close to R = 0, exactly R = 0.01 so the loading cylinder does not come off the sheet. The SN lines for two material are presented, Fig. 6 and Fig. 7.

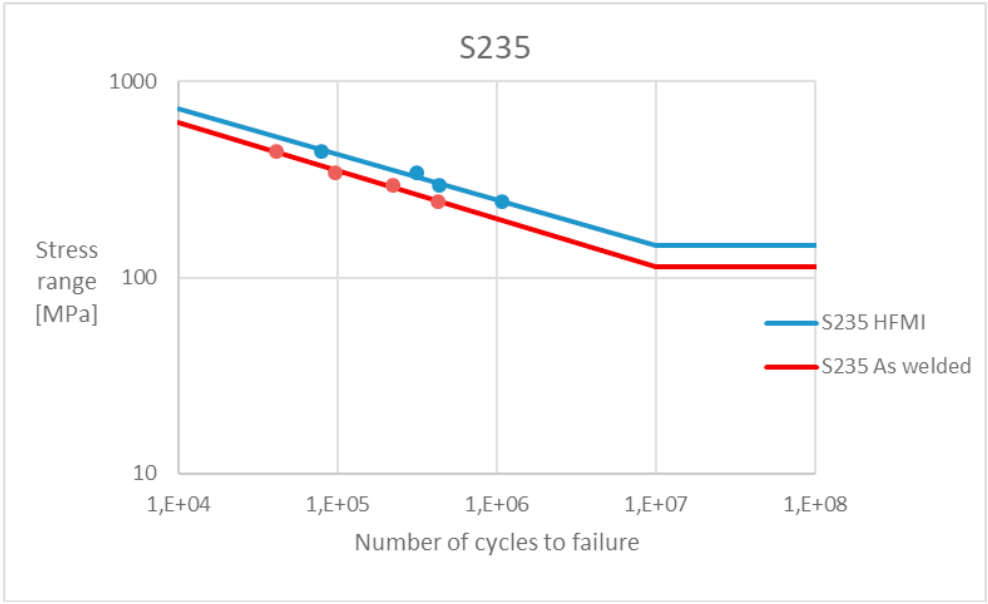


Fig. 6. The mean SN lines for stress ratio R = 0.01, structural steel S235 of thickness 15 mm, hot-spot stress.

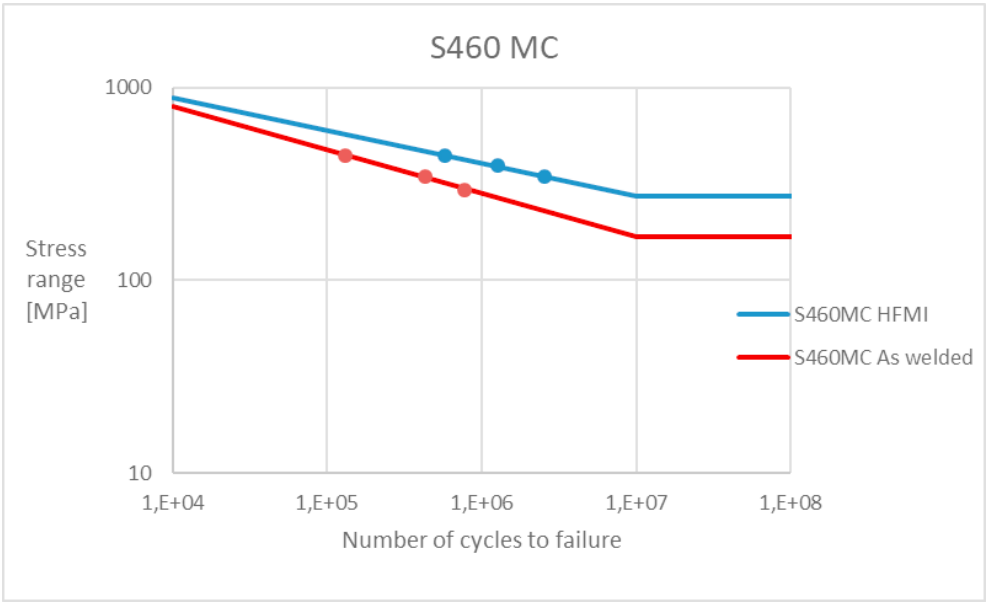


Fig. 7. The mean SN lines for stress ratio R = 0.01, structural steel S460 MC of thickness 15 mm, hot-spot stress.

## 4. Axial sample (15 mm)

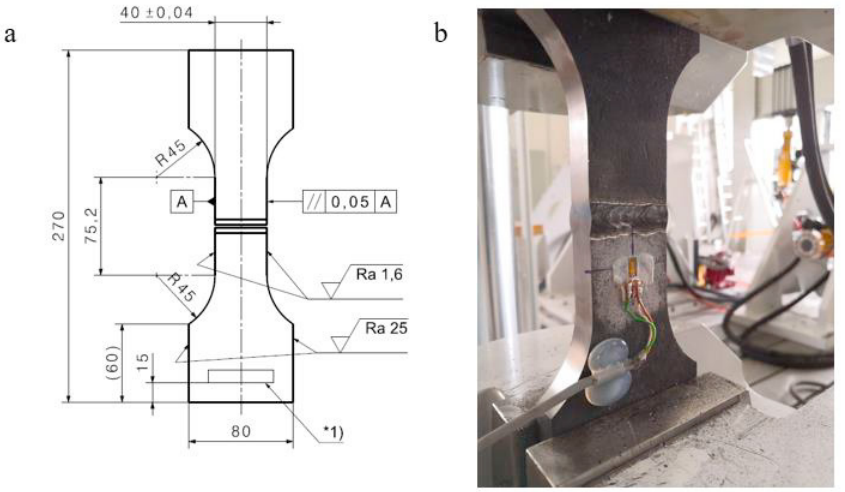


Fig. 8. (a) The 15 mm test sample; (b) The sample during the test.

A 15 mm thick sample for axial testing was crafted from S355NL steel. A Double-V butt weld using method 135 (Gas Metal arc Welding) was selected for sample fabrication. A diagram of the sample is provided below. The loading ratio was set at R = 0, and a 5 mm diameter pin was utilized for the HFMI application. The average S-N curve was assessed, and a graph indicating the fatigue limit at 10 million cycles was plotted. The HFMI method markedly enhances fatigue life, while the slope of the S-N curve remains unchanged.

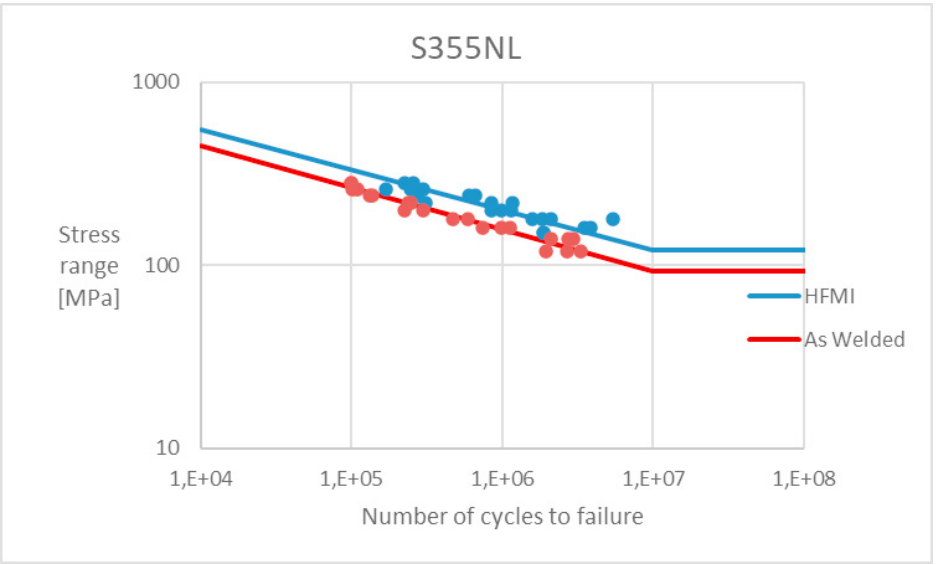


Fig 9. The mean SN lines for R = 0, structural steel S355NL of thickness 15 mm.

For these samples, residual stress was assessed using X-ray diffraction. The most pronounced diffraction lines from the primary phase (martensite) with a body-centered cubic (BCC) crystallographic lattice were utilized to determine biaxial stress. The relevant crystallographic lines were (0 1 1), (0 0 2), and (1 1 2). Implementing the HFMI method heightened the residual stress, subsequently delaying crack initiation at the weld toe. This residual stress persisted in the material even after 10 million cycles at the fatigue limit.

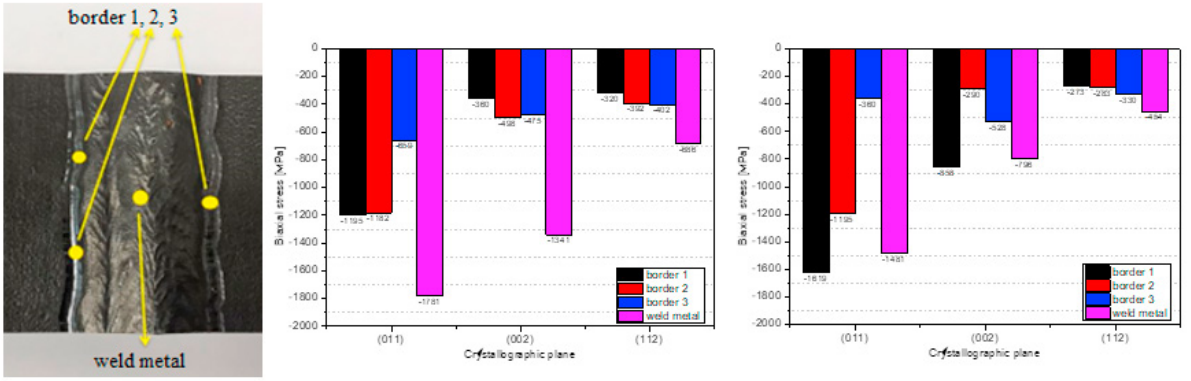


Fig.10. (a) Positions for measurement; (b) HFMI; (c) HFMI after loading by 10 million cycles.

## Conclusion

The test results for sheets with a thickness of 15 mm aligned with the recommendations. It was confirmed that the HFMI method is suitable for sheets as thick as 90 mm. For sheets with a thickness of 4 mm, adjustments to the pin diameter or pressure plate may be required. It has been determined that the residual stresses introduced by the HFMI method remain undissolved even after loading. Changes in the microstructure due to HFMI and roughness analysis are the subjects of ongoing research.

## Acknowledgments

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