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Preliminary communication

Improving Welding Quality on Zacns 98 m³ Wagon Underframe

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Abstract: The Zacns 98 m³ wagon is a wagon with a tank intended for the transportation of dangerous goods in a liquid state. Accidents caused by faulty production can have serious consequences for material goods and human health. It is therefore necessary to pay particular attention to the quality of the production process. The wagon itself consists of two parts: the tank and the underframe. These and other components are joined together using welding technology. The quality of the weld seams on the underframe, in particular the weld seams that belong to weld seam quality class CP B1 or CP B2 according to the HRN EN ISO 15085-3 standard, is the focus of the quality assurance system. Non-destructive surface and volume tests must be carried out on such weld seams and the results, which indicate problems in the welding process, must be closely monitored. This article presents welding and quality control systems for CP B1 and CP B2 performance class welds. In addition to the technologies of welding and quality control, the authors intend to show the quality level over a longer period and propose measures to improve it. The experimental study was carried out in the company Đuro Đaković Specijalna Vozila from Slavonski Brod.

Keywords: Wagon Zacns 98 m³; dangerous goods; manufacturing process quality; non-destructive examination; welding; welding process improvement

1 INTRODUCTION

Zacns 98 m³ is a four-axle wagon intended for the carriage of dangerous goods in liquid form by rail in accordance with international regulations (RID). The wagon is designed for use on rail infrastructure with a standard track width of 1435 mm [1]. Fig. 1 represents the 3D model of the wagon.

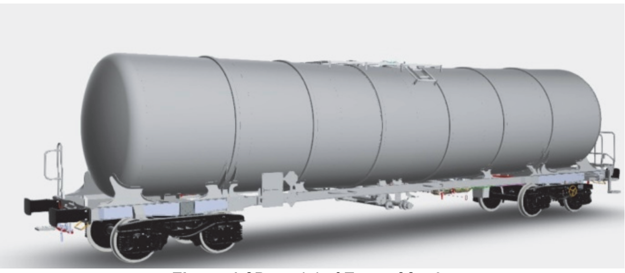

Figure 1 3D model of Zacns 98 m³ wagon

The maximum speed of the wagon is 120 km\h when empty and 100 km\h with an axle load of 22,5 tons. The T3 temperature range [2] was considered in the design, which means that performance is guaranteed at outside temperatures between –25 °C and +45 °C. Basic constituent elements of the wagon are tank, tank holders and underframe. Fig. 2 represents the wagon underframe.

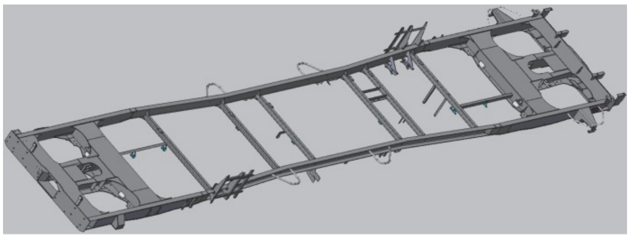

Figure 2 3D model of Zacns wagon underframe

Finite Element Method (FEM) analysis of the upper and lower underframe surfaces [3] shown in Figs. 3 and 4 shows the expected stress distribution in use. Similar FEM-based studies were conducted by Saito et al. [10] for wagon frame stress assessment.

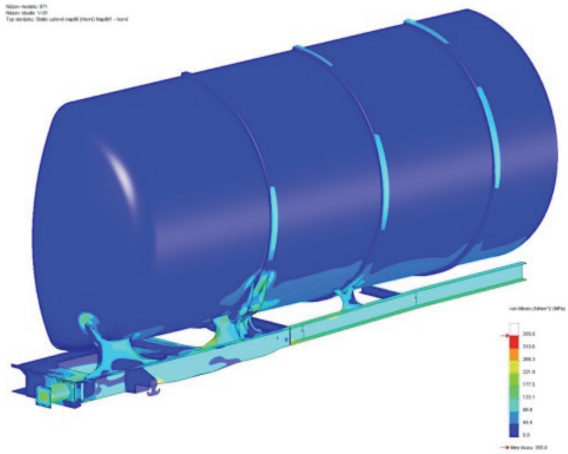

Figure 3 Upper surfaces stress distribution

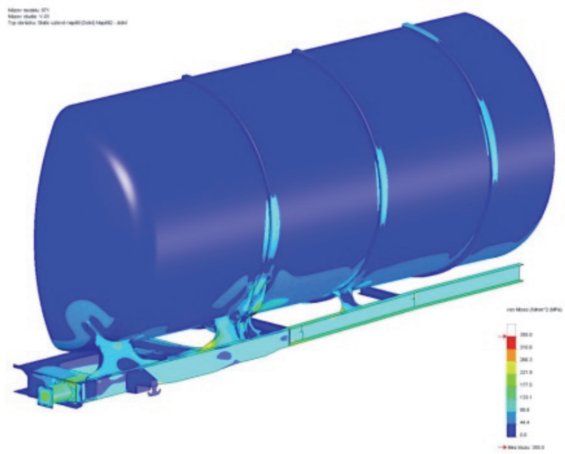

Figure 4 Lower surfaces stress distribution

The welding quality of welds which are in the "light blue" and "light green" areas of Figs. 3 and 4, has a decisive influence on the general function and usability of the wagon's underframe. These areas each show calculated stresses between 88 N/mm² and 221,9 N/mm². According to Tab. 3 of the HRN EN ISO 15085-3 standard, these welds belong to weld performance class CP B1. The welding quality of CP B1 welds must be confirmed by surface testing (penetrant testing - PT) and volumetric testing (ultrasonic testing - UT). This article focuses on analyzing and improving the welding done on welds which belong to performance class CP B1.

2 METHODOLOGIES

The weld quality of welds belonging to performance class CP B1 was tested using one of the volumetric non-destructive testing methods (UT or RT) and one of the surface non-destructive testing methods (MT, PT or ET). The choice of the appropriate test method depends on the type and material of the welded joint and the restrictions imposed by the relevant standards [4]. The experimental results presented in this paper were obtained by using UT and PT test methods. Fig. 5 shows the tested welds on the upper side of the underframe.

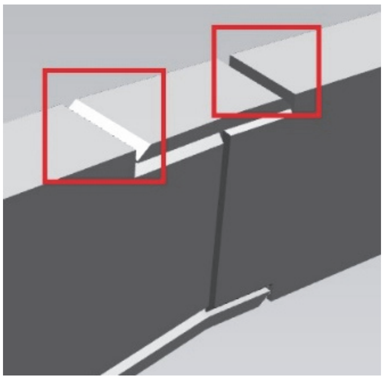

Figure 5 Examined welds from the upper side of the underframe

Examined welds from the lower side of the underframe are shown in Fig. 6.

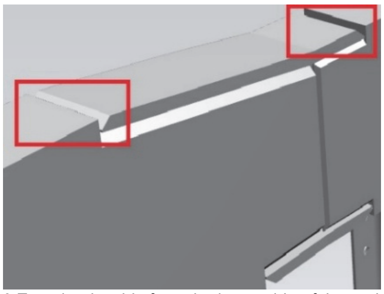

Figure 6 Examined welds from the lower side of the underframe

Technical drawing of the examined welded joints, which includes information on the type and performance class, is shown in Fig. 7.

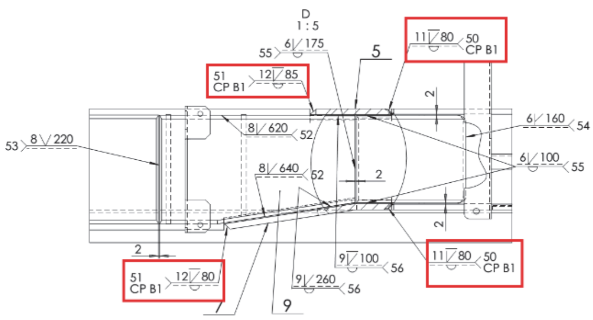

Figure 7 Technical drawing of the examined welded joints

The upper and lower side of the underframe respectively have 8 welded joints. That is 16 joints in total which by criteria defined in table 3 of the standard HRN EN ISO 15085-3, were examined UT and PT in the scope of 10%. To fulfill the requirement (10% examination scope) in an ideal case (without non-acceptable welds) at least two welds by underframe were examined. The selection of tested welds is completely arbitrary, in accordance with the requirement in Tab. 1 of the HRN EN ISO 15085-5 standard: a 10% test means a random test of 10% of the total length of the weld belonging to test class CT2, or a 100% test of one of the ten welds belonging to test class CT2. If the examined welded joint is not acceptable, the scope of testing must be extended to two additional joints belonging to the same relevant production group (same welder stamp, WPS and type of welded joint).

UT and PT tests were carried out on the first underframe in the series with the designation DP-1 to assess the welding quality of weld joints in performance class CP B1. After the test, the data collected was analyzed. Depending on the success of the welding (percentage of defects out of the total number of joints tested), changes were made to the welding process to improve the overall quality. The evaluation of the results achieved by the introduced improvements to the welding process was done by collecting welding data over a longer period (welding underframe 2 to 7). In Chapter 4, Conclusions, the authors have shown the general trend of the welding quality and the efficiency of the implemented improvements.

3 EXPERIMENTAL INVESTIGATON

The test scope of 100% was carried out with the intention of obtaining an objective picture of the welding quality on the DP-1. Fig. 8 shows the exact position and marking technique of the weld seams on the top and bottom of the underframe.

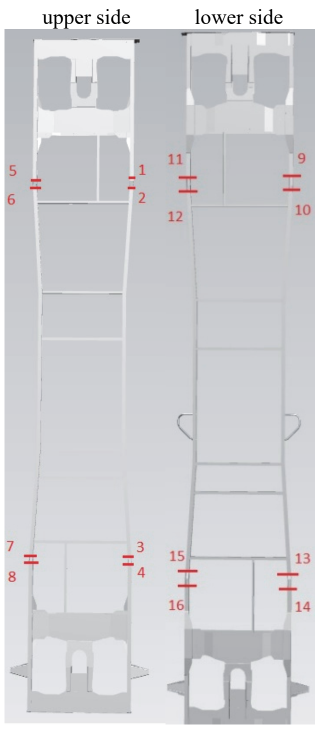

Figure 8 Location of the examined welds on the underframe

Ultrasonic examination was performed using equipment:

1) UT device: GE Phasor HS,
2) UT probes: MSEB 4, MWB 70-4, PAUT 4 MHz 16 elements,
3) Calibration samples: V1, V2,
4) DAC calibration sample 300 × 30 × 20 mm, with two φ3 mm side drilled holes located within the first and third quarters of the sample.

Fig. 9 shows UT devices and accompanying calibration samples.

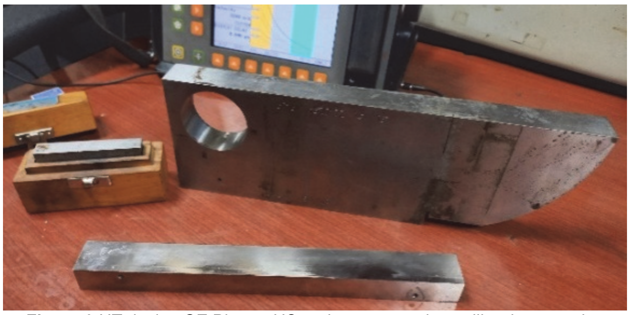

Figure 9 UT device GE Phasor HS and accompanying calibration samples

The calibration of the ultrasound system for the test (UT path and sensitivity) was performed according to HRN EN ISO 17640, also considering all positive practices available in the literature [5]. The calibration of the straight probe UT MSEB 4 on the corresponding ultrasonic path was performed on the calibration sample V1 (25 mm). The exit point of the angled probe MWB 70-4 was confirmed with the calibration sample V2, while the correction of the angle was performed with the calibration sample V1. A radius of 25 mm on calibration sample V2 was used to adjust the UT path to the correct value. The sensitivity of the system was configured by creating a DAC (distance-amplitude) curve on a special calibration sample made of the same material as the tested element (see Fig. 10).

Figure 10 Calibration sample used for sensitivity configuration

The final form of DAC curve used for assessment of found indications is shown in Fig. 11.

Figure 11 Final form of DAC curve

UT examination of weld number 1 on the upper side of the underframe confirmed the existence of defects in accordance with HRN EN ISO 11666, located in the root and fill area of the weld. Fig. 12 shows a scan of the defect located in a root of the weld.

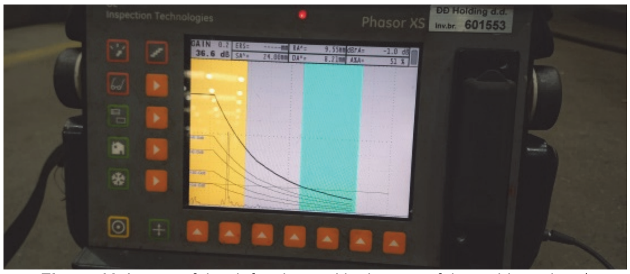

Figure 12 A scan of the defect located in the root of the weld number 1

The exact defect location was determined via UT device screen (UT path) and marked on the examined weld measuring from the head of the UT probe shown on Fig. 13.

Figure 13 Measuring defect location on the examined weld no. 1

The presence of the flaw found was confirmed by re-examining the weld using phased array UT technology in accordance with EN ISO 19285. Fig. 14 shows the same defect in the root of weld 1, this time as a sectorial scan (S-scan).

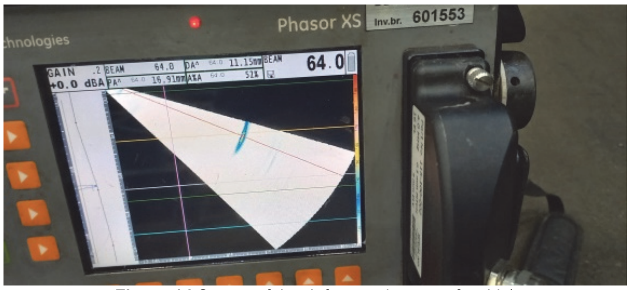

Figure 14 S scan of the defect on the root of weld 1

In addition to defects in the root of the weld, in the filled area was also found another defect shown in Fig. 15.

Figure 15 A scan of the defect found in the filled area of the weld

Defect location was marked on the weld by using a measuring tool from the head of the UT probe, shown in Fig. 16.

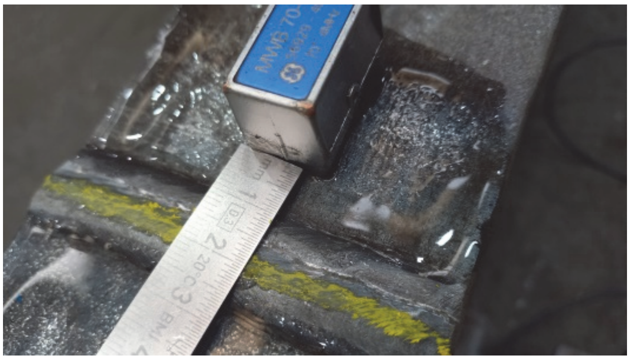

Figure 16 Marking the defect in the filled area of weld no. 1

Phased array UT technology confirmed the existence of a defect, shown here in Fig. 17 as a sectorial scan.

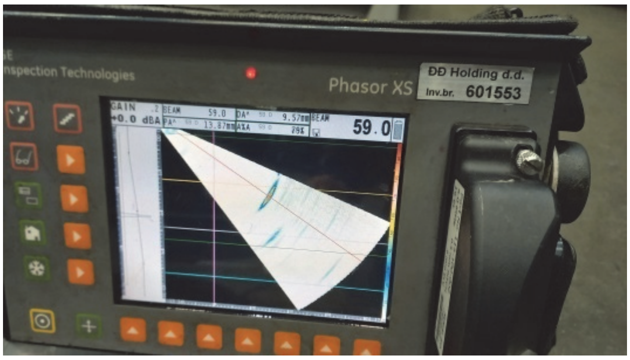

Figure 17 S scan of the defect in the filled area of weld no. 1

Example of the UT examination performed on the lower part of the underframe is presented on weld number 11. Fig. 18 shows the A scan.

Figure 18 A scan of the defect located in the root of the weld no. 11

Distance of the defect from the head of the UT probe was shown in Fig. 19.

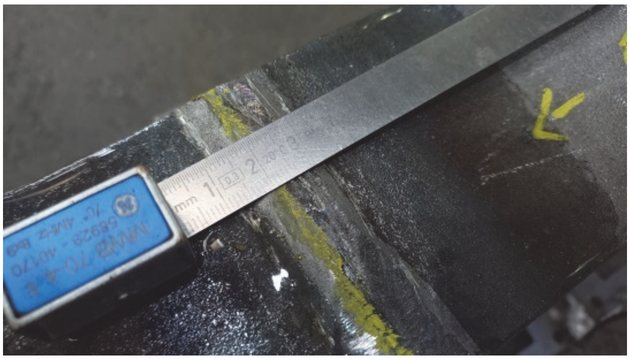

Figure 19 Marking defect location in the root of the weld number 11

Phased array UT technology was used to confirm the existence of the defect, represented here in Fig. 20.

Figure 20 S scan of the defect located in the root of the weld no. 10

Penetrant (PT) examination was performed on non-acceptable welds after their reparation. For welded joints that were necessary to be completely repaired (whole length of the weld), for example weld no. 1, welding technological addition was also included in the repair process. The PT examination was performed in accordance with HRN EN ISO 3452-1, and defect classification in accordance with HRN EN ISO 23277. Fig. 21 shows the results of the examination performed after the repair of weld no. 1.

Figure 21 PT examination of welded joint no. 1 after repair

Summary of the examination results of CP B1 performance class welded joints located on the upper side of the underframe are shown in Tab. 1.

Table1 Summary of the examination results on the underframe 1 - upper side

Number of the welded joint	Examination method	Defect type\ Defect location
1	UT+PT	Filled area, Root
2	UT+PT	No defect
3	UT	Filled area, Root
4	UT	Filled area, Root
5	UT	Filled area, Root
6	UT	Filled area
7	UT	Filled area
8	UT	Filled area

Tab. 2 shows summary of the examination results on underframe 1 - lower side.

Table 2 Summary of the examination results on the underframe 1 - lower side

Number of the welded joint	Examination method	Defect type\ Defect location
9	UT	No defect
10	UT	No defect
11	UT+PT	Root
12	UT	Root
13	UT	Root
14	UT	Root
15	UT	Root
16	UT+PT	No defect

After performing the UT and PT inspection of the base frame, the following results were obtained: out of a total of 16 welds, 11 defects were found in accordance with the specified acceptance criteria according to HRN EN ISO 11666. The percentage of defects found was calculated using the following Eqs. (1) and (2):

$$P_{\text{defects}} = \frac{N_{\text{non-acceptable}}}{N_{\text{total number}}} \times 100, \tag{1}$$

$$P_{\text{defects}} = \frac{11}{16} \times 100 = 68,75 \approx 69\% \tag{2}$$

where: $N_{\text{non-acceptable}}$ - number of non-acceptable welds found after UT examination; N_{total} - total number of UT examined welds.

The percentage of defects after the UT test of 69% is not acceptable from the point of view of sustainable production. The test results were analyzed according to the Six Sigma methodology [6]. Fig. 22 shows the procedure used:

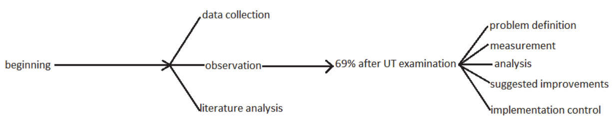

Figure 22 Diagram of the six-sigma model implementation

The analysis of the causes of the high number of deficiencies after the UT audit led to the following conclusions:

1) Welding of welded joints belonging to performance class CP B1 may only be carried out by certified and verified welders,
2) It is necessary to keep detailed statistics on the success of welders during their work in ĐĐSV.
3) Welding of such joints may only be carried out in the first shift (07.00-15.00)-The welding process is sensitive to operator fatigue and inconsistent joint preparation. Petrović et al. [9] emphasized the impact of shift scheduling and human factors on weld quality.
4) Welding must not be carried out at weekends.
5) Constant supervision by members of the welding supervisor is required.
6) Compliance with the specified WPS by the welders must be monitored.
7) Additional training of welders must be carried out regularly.
8) Rotation of welders must be kept to a minimum.
9) Quality must be financially rewarded, not just quantity.

The implementation of the new regulations began with the welding of the next underframe, DP - 2. In the period from 05.02.2024 - 22.02.2024, the following results were achieved, which are shown in Tabs. 3 to 9. Tab. 3 shows the summarized results of the UT test on DP2 from the top side, the defect percentage was 19%.

Table 3 Results of UT examination on underframe no. 2 - upper side

Number of the welded joint	Examination method	Defect type\ Defect location
1	UT	No defect
2	UT	No defect
3	UT	Root
4	UT	Root
5	UT	No defect
6	UT	No defect
7	UT	Filled area
8	UT	No defect

Tab. 4 shows examination results of the DP 3 - lower side with defect percentage of 0%.

Table 4 Results of UT examination on underframe no. 3 - lower side

Number of the welded joint	Examination method	Defect type\ Defect location
1	UT	No defect
2	UT	No defect
3	UT	No defect
4	UT	No defect
5	UT	No defect
6	UT	No defect
7	UT	No defect
8	UT	No defect

UT examination results of DP 3 - upper side can be seen in Tab. 5, with defect percentage of 13%.

Table 5 Results of UT examination on underframe no. 3 - upper side

Number of the welded joint	Examination method	Defect type\ Defect location
9	UT	No defect
10	UT	No defect
11	UT	Root
12	UT	No defect
13	UT	No defect
14	UT	No defect
15	UT	No defect
16	UT	Root

DP 4 - upper side UT examination results are presented in Tab. 6; percentage of defects is 13%.

Table 6 Results of UT examination on underframe no. 4 - upper side

Number of the welded joint	Examination method	Defect type\ Defect location
1	UT	No defect
2	UT	No defect
3	UT	Filled area, Root
4	UT	Filled area
5	UT	No defect
6	UT	No defect
7	UT	No defect
8	UT	No defect

Tab. 7 shows UT examination results of DP 5 - upper side with 0% percentage of defects.

Table 7 Results of UT examination on underframe no. 5 - upper side

Number of the welded joint	Examination method	Defect type\ Defect location
1	UT	No defect
2	UT	No defect
3	UT	No defect
4	UT	No defect
5	UT	No defect
6	UT	No defect
7	UT	No defect
8	UT	No defect

Finally, DP 7 - lower side examination results are presented in Tab. 8 with percentage of defects being 13%.

Table 8 Results of UT examination on underframe no. 7 - lower side

Number of the welded joint	Examination method	Defect type\ Defect location
1	UT	No defect
2	UT	Filled area, Root
3	UT	No defect
4	UT	No defect
5	UT	No defect
6	UT	Filled area
7	UT	No defect
8	UT	No defect

4 CONCLUSIONS

The initial UT inspection defect percentage of 69% was reduced to an average of 9,67% during the testing phase. The results of this work reflect the findings of other authors who have dealt with similar problems [7] and confirm the suitability of the six-sigma method for improving overall weld quality. This method was also used in quality improvement studies by Novaković et al. [8].

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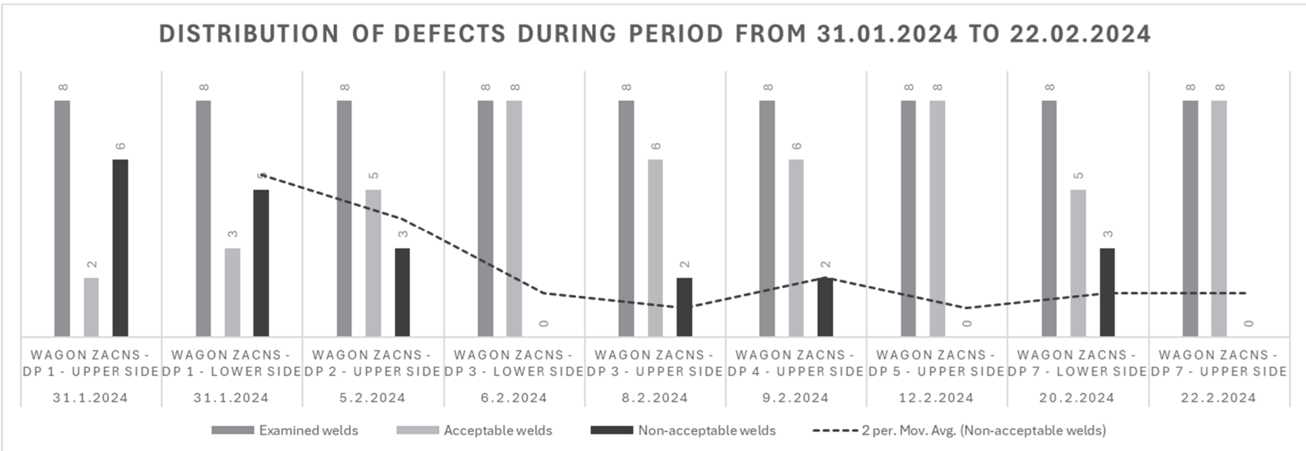

Figure 23 Distribution of defects after UT examination during period of 31.01.2024 to 22.02.2024

5 REFERENCES

[1] HRNEN ISO 15085-3. (2008). Railway applications - Welding of railway vehicles and components - Part 3: Design requirements.

[2] HRNEN ISO 15085-5. (2008). Railway applications - Welding of railway vehicles and components - Part 5: Inspection, testing and documentation.

[3] HRNEN ISO 17640. (2010). Non-destructive testing of welds - Ultrasonic testing - Techniques, testing levels and assessment.

[4] HRNEN ISO 3452-1. (2021). Non-destructive testing - Penetrant testing - General principles.

[5] Ahmed, A. & Sørensen, J. D. (2021). Probabilistic models for reliability-based inspection planning of welded joints. *Journal of Structural Integrity*, *28*(2), 107-116. https://doi.org/10.1016/jsi.2021.03.005

[6] Ebrahimi, M., Zarei, M., & Akbari, H. (2022). Evaluation of phased array ultrasonic testing for welded joints. *NDT & E International*, *129*, 102647. https://doi.org/10.1016/j.ndteint.2022.102647

[7] Kovačević, L., Grgić, M., & Perić, M. (2023). Fatigue life of welded joints in freight wagons under dynamic loads. *Engineering Structures*, *278*, 115654. https://doi.org/10.1016/j.engstruct.2023.115654

[8] Novaković, B., Marković, D., & Tomić, M. (2021). DMAIC method application in quality improvement of welded structures. *International Journal of Industrial Engineering*, *28*(1), 55-66.

[9] Petrović, R., Jurić, I., & Bačić, D. (2024). Influence of shift scheduling and operator fatigue on welding defect rates. *Welding and Fabrication Technology Journal*, *42*(1), 22-29.

[10] Saito, Y., Tanaka, K., & Watanabe, H. (2020). Stress concentration and deformation in freight wagon frames: FEM analysis. *Railway Engineering Research*, *17*(3), 183-190.

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