JOURNAL OF THEORETICAL
AND APPLIED MECHANICS
63, 3, pp. 461–469, Warsaw 2025
https://doi.org/10.15632/jtam-pl/200388

DURABILITY TESTS FOR THE AUTOMOTIVE INDUSTRY

Tadeusz SZYMCZAK[1*], Zbigniew L. KOWALEWSKI[2], Adam BRODECKI[2]

[1] *Vehicle Type-Approval & Testing Department, Motor Transport Institute, Warsaw, Poland*
[2] *Department of Experimental Mechanics, Institute of Fundamental Technological Research, Polish Academy of Sciences, Warsaw, Poland*

*corresponding author, *tadeusz.szymczak@its.waw.pl*

This study focuses on component durability testing methods and their application in the automotive industry. These types of tests can be used to assess various objects with simple and complex geometries and a range of dimensions, manufactured using certain structural materials, including 6005 T6 aluminium alloy and S700MC high-strength steel. The test results characterise the component response at 2×10^6 loading cycles, and the crack trajectories are analysed after a high number of cycles. The influence of the welding process on the tensile mechanical parameters of the aluminium alloy and steel is also discussed, and fatigue behaviour of S700MC and its weld is illustrated.

Keywords: durability test; fatigue; cracks; fracture; coupling; vehicles.

Articles in JTAM are published under Creative Commons Attribution 4.0 International.
Unported License https://creativecommons.org/licenses/by/4.0/deed.en.
By submitting an article for publication, the authors consent to the grant of the said license.

1. Introduction

Durability tests have been used to examine the fatigue resistance of different components (Berger *et al.*, 2010; Creager *et al.*, 2015; Szymczak *et al.*, 2022a; 2022b). Generally, they are employed in two branches of industry: aviation (Berger *et al.*, 2010; Creager *et al.*, 2015) and automotive (Szymczak *et al.*, 2022a; 2022b), where many working elements operate under cyclic loading. From an engineering perspective, this indicates that inspections should be performed to capture crack occurrence, as cracks can lead to element's failure.

Different types of testing stands can be used to examine durability. One type uses two-level platforms for mounting the tested objects and for subsequent examinations (Servotest Systems; SSTM, 2019). Depending on their complexity, they enable different types of loading applications such as cyclic and dynamic torsion, dynamic axial loading, and thermal cycles (Servotest Systems). More complex multi-element devices enable biaxial loading (i.e., horizontal and perpendicular) (MTS). Testing stands can be used in conjunction with environmental chambers which control the temperature range from −40 °C to 120 °C and provide special conditions with the application of water, salt and mud. Multiaxial systems are recommended for examining the mechanical resistances of components of different shapes and dimensions (MTS). Multi-servo actuators and closed-loop feedback enable effective testing of vehicles (Instron; Wielton Group).

Research groups have focused on different aspects of durability tests, such as stochastic changes in selected physical quantities during road testing by a target dynamic system comprising a potentiometer, an accelerometer, and a strain gauge, and their analyses (Jung *et al.*, 2003).

Ministry of Science and Higher Education
Republic of Poland

The publication has been funded by the Polish Ministry of Science and Higher Education under the Excellent Science II programme "Support for scientific conferences".
The content of this article was presented during the 40th Danubia-Adria Symposium on Advances in Experimental Mechanics, Gdańsk, Poland, September 24–27, 2024.

This type of data is also analysed using the acceleration time signal and frequency response fraction to calculate the displacement and shock response functions (Halfpenny, 2006). A Weibull analysis was also performed for stochastic cycles (Król & Gasiak, 2018).

In another study, the authors used the stress-strain relationship to determine the limits of the cyclic force (Gowda *et al.*, 2015). If the tests are performed at different operational times, then comparisons can be made (Stembalski *et al.*, 2024).

Typical fatigue tests are directly used in the automotive industry to determine the mechanical resistance of components used for vehicle coupling, such as balls and drawbar beams, as shown in Fig. 1. The coupling components can be used at a constant high level (Fig. 1) or three levels using screws, as shown in Fig. 2. In these cases, the component can operate at permissible loading values determined in the durability testing. Operational loading at values within the defined limit does not cause any deformation or cracks owing to coupling.

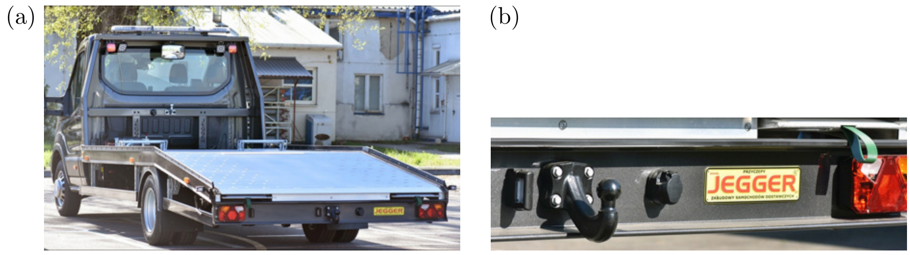


Fig. 1. Car transporter having a JEGGER regular platform with a coupling function using the A50-X ball, made of steel and aluminium alloy.

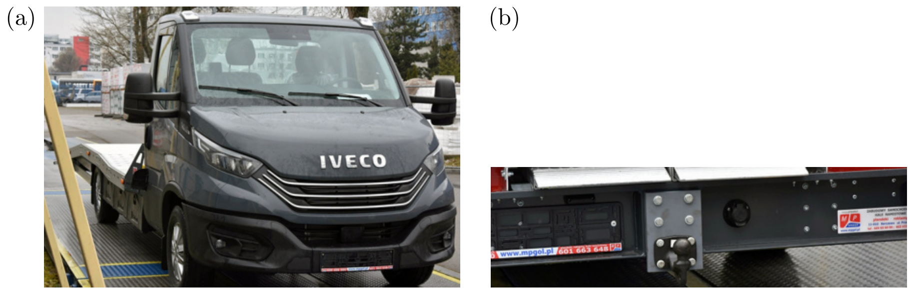


Fig. 2. Car transporter having an MP Group irregular platform with a multi-levelled coupling function using the A50-X ball, made of steel and aluminium alloy.

This kind of test is not trivial but a complex one, because of the weight and dimensions of the tested object, as the values of these physical parameters are often between 200 kg–400 kg and 3.5 m × 2 m, respectively. From the practical point of view, the mounting manner is very important and should be done according to the operation process. This requires a conception and a lot of time to connect the tested object with a platform. Therefore, in the case of towing frames, this kind of component was examined in a reversed position where the platform followed the vehicle mass, while in the case of platforms (6 m × 2 m), it was tested as a complete one with a wheel axis and suspension at an operational orientation. Those approaches can be indicated as the requirements for examining huge components. Moreover, an inspection of the tested object and physical parameters used in the tests should be done every day, while the tests require 2 weeks in continuous mode, i.e., day and night. Another significant feature of the experiment is connected with type approval, because positive results enable applying to the approval authority (TDT – transport technical supervision, Poland) for issuing a certificate of approval. This kind of final result enables the mounting of a component in a vehicle and it can be called "made in Poland" for sale in the EU and other countries of the World. Moreover, the experiment with a component such as a platform for a vehicle for transport vehicles, towing frames to recovery vehicles and coupling adapters can be conducted in a technical service approved by the TDT. Sometimes, the stand test should be supported by static and fatigue experiments if a joining technology is selected for qualification concerning its quality or modelling. Taking this information into consideration, the paper's aim was proposed: a multistage mechanical approach to testing components and their joints enables determining their technical quality and type approval. Therefore, the paper collects a lot of details of experiments on components, specimens of parent materials and their weld covering aluminium alloy and modern high-strength steel.

2. Details of experiments

This kind of experiment requires dedicated research equipment such as a digital controller (Instron Structural Testing for example), software (RSview used in stand tests), computer, mobile servo-actuator (Saginomiya ± 30 kN at angular position of piston rod applied for examining) and a huge T-slot platform with a seismic mass (the laboratory section component of the Department of Type-Approval and Testing of Motor Transport Institute). The digital controller should be used to achieve the required technical level for durability tests. Such a device enables the collection of different signal types such as displacement, force, rotation angle, and torque. It is typically equipped with several measurement cards to acquire the digital and analogue signals. A computer with special software for tuning, testing, and data collection supports durability testing.

The main parameters of the durability tests, such as amplitude and frequency, can be established basing on specific requirements. For example, UN Regulation No. 55 (UN/ECE, 2010) was used in the tests on mechanical coupling devices. Information about the direction of the force vector (an angle for the actuator) is also provided in the regulation, as shown in Fig. 3. Additionally, it indicates the basic regime of the mounting components used for the examination. No deviations from the procedure were allowed because durability tests play a crucial role in component qualification concerning its quality, approval, application, and final sale.

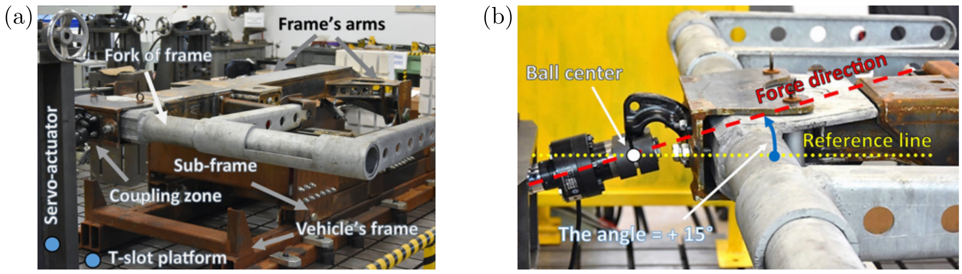


Fig. 3. Towing frame (for recovery vehicles on highways and expressways) on a stand testing platform: (a) a general view; (b) a mechanical connection of the servo-actuator and frame through a spherical grip and A50-X coupling ball.

This approach was supported by mechanical tests on specimens that assessed the base metal and its weld. It is important to determine the following fundamental mechanical parameters: Young's modulus, elastic limit, yield stress, and ultimate tensile strength. These can be used to determine the welding quality, quality of the welding technology, and model the component behaviour under cyclic loading. Therefore, these tests were performed for the 6005 T6 aluminium alloy and its weld. The specimens (Figs. 4 and 5) were cut from an aluminium alloy plate (Fig. 4) using electrical discharge machining (EDM).

All the tests were performed at room temperature using an 8874 Instron servo-hydraulic testing machine and a 2610 Instron extensometer, as shown in Fig. 5. Considering the aim of the test, represented by the automotive component approval, faces and roots of welds were not removed. This enabled the collection of data on the joint and comparison with the base material.

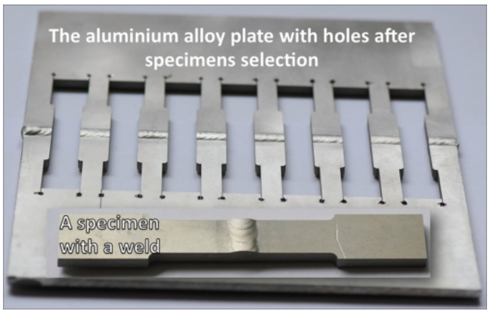


Fig. 4. Aluminium alloy plate after specimens manufacturing for examination of mechanical resistance of the weld.

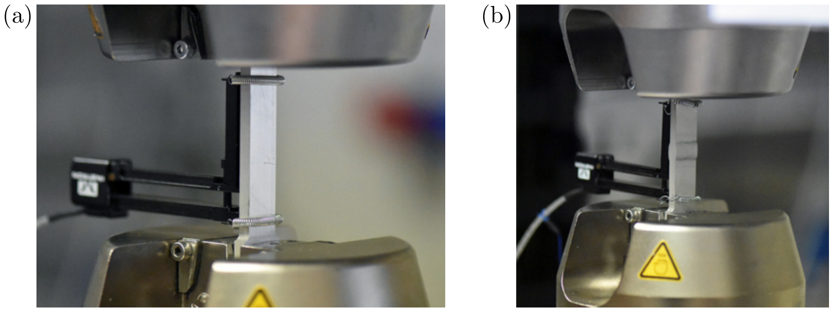


Fig. 5. Aluminium alloy specimen in 8874 Instron servo-hydraulic testing machine: (a) a base material; (b) with a weld.

3. Results

The results of the durability tests were strongly dependent on the type of signal used to control the test stand. If a signal force is applied, the changes in displacement values can be collected. They should be analysed at various stages of cyclic loading, including the last stage, as shown in Fig. 6. Even small differences in the responses of a tested object can be effectively demonstrated by applying this procedure. This is particularly evident in the changes in the minimum values of the captured signal.

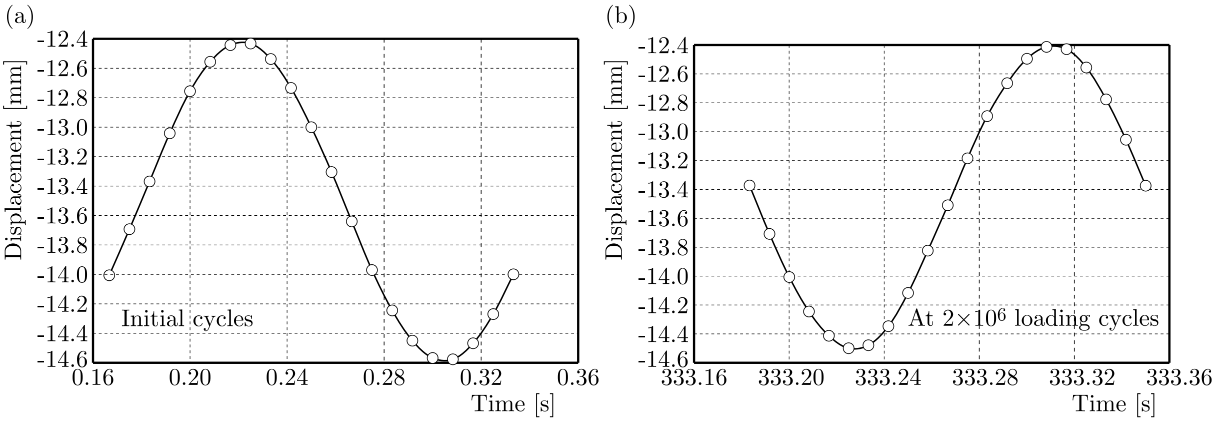


Fig. 6. Displacement captured during the durability test of a towing frame for a heavy recovery vehicle (test carried out at amplitude of ±18.6 kN and frequency of $f = 6\,\mathrm{Hz}$).

The same type of loading signal is used for other mechanical coupling devices such as adapters for SUVs in the USA trade market. Although construction of the components is not complex, a crack occurred in this case. This is visible in the region close to the weld as an effect of the joining technology (Fig. 7).

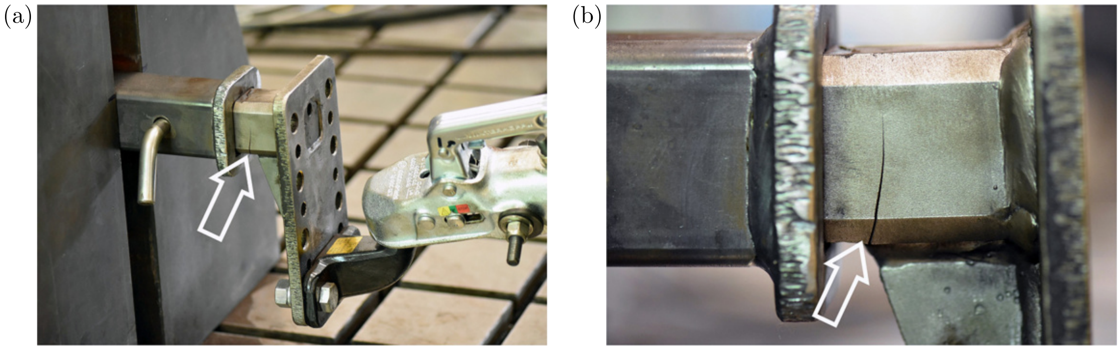


Fig. 7. Cracks in the adapter to SUV from USA market for a coupling after 1.7×10^6 loading cycles under amplitude of ± 12.33 kN and frequency $f = 5$ Hz.

This type of results, due to cyclic loading, is visible in the aluminium alloy; however, in this case, hairline cracks were the dominant type of damage, as shown in Fig. 8a. In steel, cracks are typically more visible and easier to detect. These reflect the low quality of the joint and its unfavourable influence on the base material of the vehicle frame, as shown in Fig. 8b.

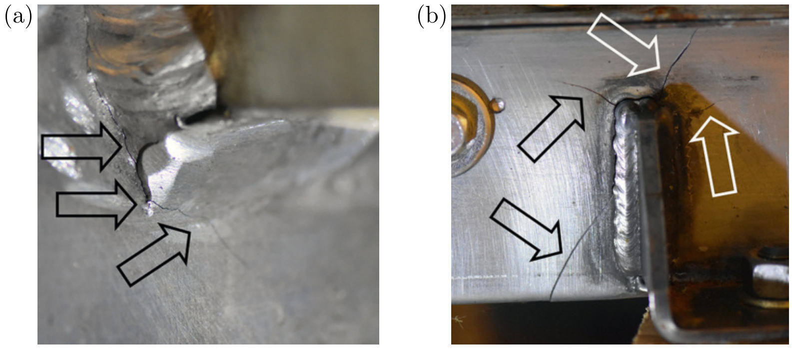


Fig. 8. Cracks in the platform with a coupling function after 2.24×10^6 loading cycles under amplitude of ± 10.3 kN and frequency $f = 4$ Hz for: (a) aluminium alloy; (b) steel.

Notably, visual observations, macrophotographic techniques, and dye-penetrant methods enable identification of cracks. The defect inspection method depends on the applied engineering materials. Thus, in the case of typical steel grades (Figs. 7 and 8), observation or microphotography techniques are very suitable, whereas in the case of aluminium alloy or high-strength grades, these methods are not sufficient because of the occurrence of hairline cracks.

Therefore, if a component is made of an aluminium alloy or a high-strength steel, a macrophotography technique (Fig. 9) at negative and positive loading values, as well as a dye-penetrant technique, are recommended.

Fig. 9. Hair cracks in a component made of high-strength steel (S700MC) using dye-penetrant technique after 2×10^6 cycles.

The second stage of the durability test is determining the causes of cracks. To achieve this goal, tensile tests of welding joints are helpful because the recommended basic mechanical parameters of the object are selected by comparing the tensile characteristics of the base material and its weld, as shown in Fig. 4. Differences in the tensile characteristics of the base metal and welded material can be significant, reaching 120 MPa, as shown in Fig. 10. This also indicates that the fatigue resistance of the joint was lower than that of the alloy. Therefore, this region should be inspected during durability tests and considered for the mechanical parameters for the failure effect analysis approaches. This can also be selected as a feature for the qualification of the welding technology; however, the joining method should be improved.

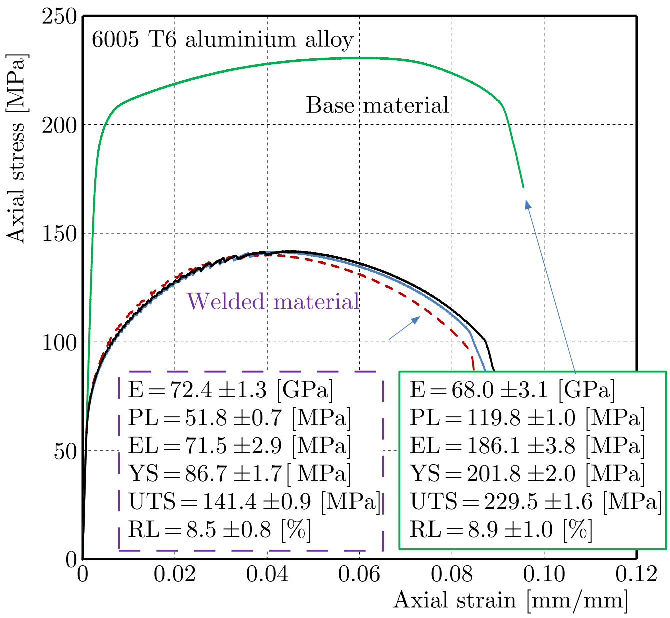


Fig. 10. Tensile characteristics of 6005 T6 aluminium alloy and its weld: E – Young's modulus, PL – proportional limit, EL – elastic limit, YS – yield stress, UTS – ultimate tensile strength, RL – relative elongation.

Differences between the welded and base materials were observed in the fracture zones. The alloy exhibited brittle failure (Fig. 10), whereas the joint exhibited ductile failure (Fig. 11). Moreover, in the case of the weld, a range of heat-affected zones was clearly observed.

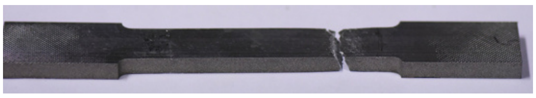
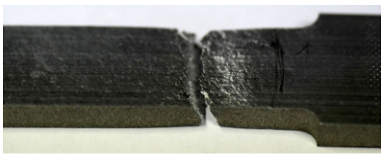
(a)  (b) 

Fig. 11. 6005 T6 aluminium alloy after tensile test.

If the welding technology is suitable for the structural material, then the mechanical parameters of the joint can reach higher values than those of the base metal, as shown in Fig. 12. This can be observed in the fracture regions because, in contrast to the weld in the case of the parent material, a shear stress component occurs, as shown in Fig. 14. This is due to the higher

(a)  (b) 

Fig. 12. 6005 T6 aluminium alloy specimen with weld after tensile test.

elongation value of the steel, as illustrated in Fig. 13. This causes the mechanical resistance of the weld to be better than that of steel under static and fatigue loading.

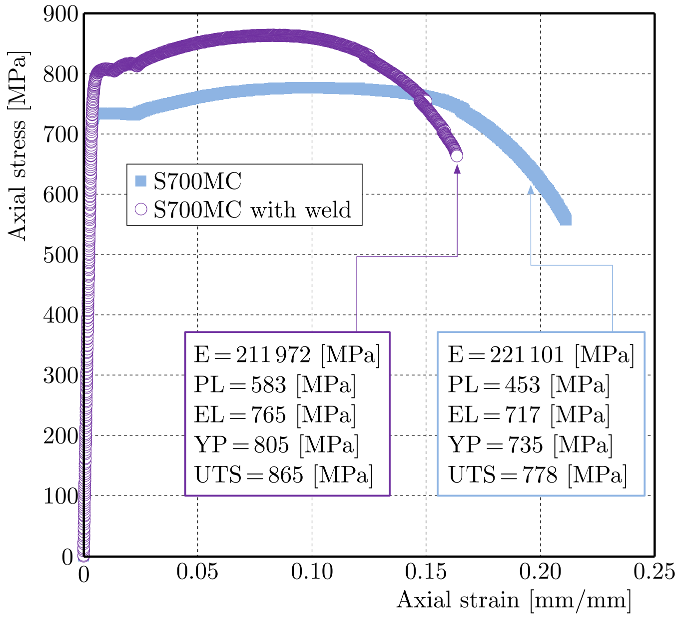


Fig. 13. Tensile characteristic of the S700MC and its weld.

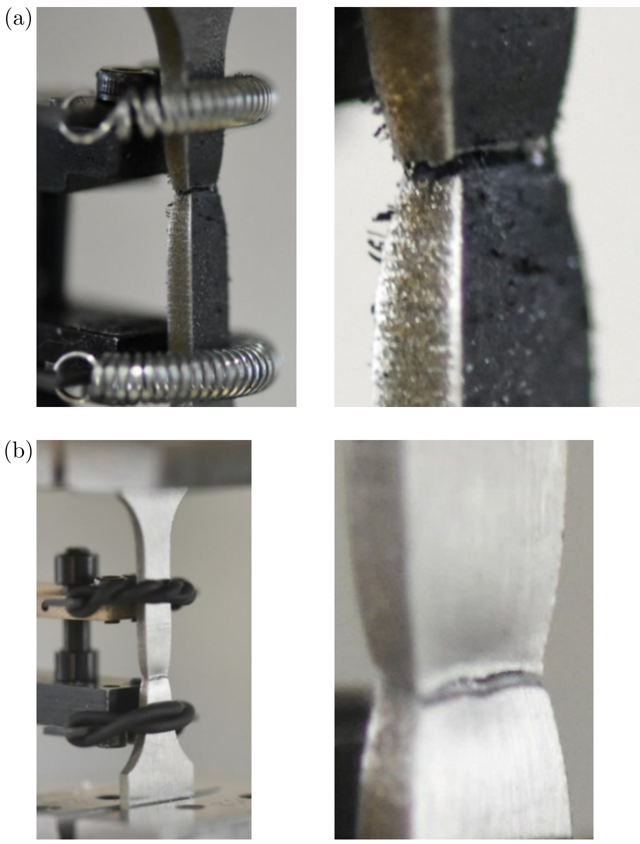


Fig. 14. Flat specimens after the tensile test: (a) S700MC; (b) the welded steel.

Nevertheless, as confirmed by the fatigue test (Fig. 15), the joint behaviour under cyclic loading was worse than that of the base metal. The difference between the fatigue limit values of the material sections was 290 MPa. This indicates that the weld is more sensitive to cyclic loading

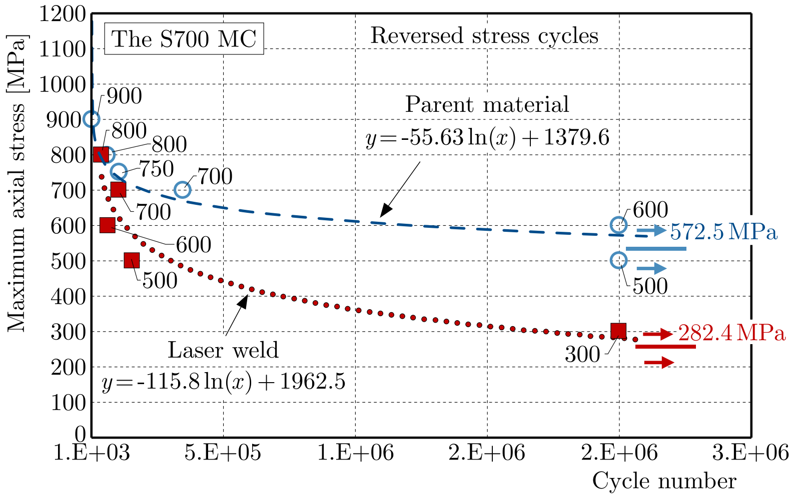


Fig. 15. Wöhler curve of the S700MC and its weld.

than the steel. This conclusion can also be drawn from the proportion of the fatigue limit values and the ultimate tensile strengths, which were 0.66 and 0.36 for the base metal and weld, respectively.

4. Summary

To determine the quality of a given object, durability testing requires the following conditions to be met:

a) an assembly should reflect the operating conditions of the object;
b) tests should be carried out for at least 2×10^6 cycles;
c) the inspection should cover all types of connections;
d) test results must indicate the causes of cracks or deformations;
e) welding technology should be qualified based on tensile and fatigue tests.

Taking into account a component type, its following regions require attention:

a) coupling zone and arms and their welds to a towing frame of a recovery vehicle;
b) a region for welding a coupling hole plate and bar for a coupling adapter to SUVs from the USA market;
c) a weld joining between an overrun section platform's frame and its subframe to auto-transporter.

References

1. Berger, H., Klein, M., Lambert, F., & Levadoux, B. (2010). Optical vibration measurement and frequency response analysis on large structures under multiple excitation load conditions. *Proceedings of ISMA2010 Including USD2010*, 1693–1702.

2. Creager, C., Johnson, K., Plant, M., Moreland, S., & Skonieczny, K. (2015). Push–pull locomotion for vehicle extrication. *Journal of Terramechanics*, *57*, 71–80. http://doi.org/10.1016/j.jterra.2014.12.001

3. Gowda, KG S., Ghai, A.S., Polisetti, S., Tiwari, S., & Ashok, B. (2015). Fatigue life prediction and durability test of passenger car Rheocast aluminium steering knuckle. *Journal of Materials Science & Surface Engineering*, *3*(1), 171–176.

4. Halfpenny, A. (2006). Method for accelerating dynamic durability tests. *9th International Conference on Recent Advances in Structural Dynamics*, Southampton, UK.

5. Instron, www.instron.com.
6. Jung, W.-W., Park, S.-C., Yoon, Y.-J., Park, S.-H., Lee, Y.-J., & Lee, M.H. (2003). Development of durability test system for automobile. *ICCSA*, October 22–25 (pp. 286–291). Gyeongju, Korea.
7. Król L., & Gasiak, G. (2018). Durability test of central differential in automotive industry. *AIP Conference Proceedings*, *2028*(1), Article 020006. https://doi.org/10.1063/1.5066396
8. MTS, www.mts.com, (access date: 07.03.2018).
9. Servotest System, www.servotestsystems.com, (access date: 07.03.2018).
10. SSTM (2019). Anthony Best Dynamics Outline Specification SSTM SP6102, issue 3, 4 pages.
11. Stembalski, M., Czarnuch, A., Szydłowski, T., & Batory, D. (2024). Assessment of the possibility of validating the durability testing method for large-sized vehicles based on changes in shock absorber characteristics – Preliminary tests. *Applied Sciences*, *14*(1), Article 127. https://doi.org/10.3390/app14010127
12. Szymczak, T., Brodecki, A., Kowalewski, Z.L., & Rudnik, D. (2022a). Mechanical investigations supported by DIC of structural components intended for operation. *Scientific Reports*, *12*, Article 19148. https://doi.org/10.1038/s41598-022-22615-0
13. Szymczak, T., Cholewiński, S., Brodecki, A., & Łączyński, J. (2022b). Mechanical coupling devices to various types of vehicles under cyclic loading. *International Journal of Automotive Technology*, *23*(1), 159–167. https://doi.org/10.1007/s12239-022-0013-2
14. UN/ECE, Regulation No 55 of the Economic Commission for Europe of the United Nations, (2010). Uniform provisions concerning the approval of mechanical coupling components of combinations of vehicles. http://data.europa.eu/eli/reg/2010/55(2)/oj
15. Wielton Group (in Polish), https://wieltongroup.com/news-press/aktualnosci/centrum-badawczo-rozwojowe-wieltonu-otwarte/, (access date: 01.07.2019).

Manuscript received December 2, 2024; accepted for publication January 22, 2025; published online May 17, 2025.