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Fatigue resistance of sheet metal sections generated by press-bolts joints in cold forming

C. Denkert[1], D. Kühne[2], R. Glienke[3], M. Fiedler[2], M. Dörre[1], W. Flügge[1] and M. Kästner[2]

[1]Fraunhofer Institute for Large Structures in Production Engineering IGP, Rostock, Germany
[2]Chair of Computational and Experimental Solid Mechanics Technical University Dresden, Germany
[3]Wismar University of Applied Sciences Technology Business and Design, Wismar, Germany

Abstract

Functional elements which are pressed in sheet metal by forming present a promising technical and economical alternative beside welded studs. Comparable to welded studs, press-bolts enable the opportunity to join parts and components in sheet metal constructions. Beyond that press-bolts offer multiple advantages due to the insertion by cold forming. One of them is that press-bolts provided defined property classes whereby offers the possibility for tightening and preloading. Thermal influence occurring in in the metal microstructure do not need to be considered and it is also possible to join coated parts. However, the insertion of these bolt elements applies a structural notch into the support structure. In respect to cyclic loaded constructions, such as railway vehicles, there is no knowledge about the fatigue resistance yet. Concepts of proof or design regulations, as they are commonly used for welded structures, are not available for such metal sections.

Keywords: mechanical joining, functional elements, press-bolt, joining, railway vehicles, sheet metal constructions

1 Introduction

One of the most important decisions for economically and qualitatively production process is the choice of the most suitable joining technology. To equip bodies of railway vehicles with various support and attachment parts, bolted joints are still first choice and state of the art. A quite representative example for the execution of such non-load carrying attachments is displayed in Figure 1. On the left hand the picture shows threaded bolts which are attached to the support structure. On the right hand the Figure 1 illustrates pneumatic lines mounted by bolting them onto the vehicle body. Welded studs are often used to provide the necessary external threads, even if this correspond with multiple disadvantages. In terms of weldability those studs do not provide any property classes to preload them in high strength. Moreover, corrosion protection and coatings must be removed in case of application. Also, thermal influences occur in the metal microstructure. Additionally, welded seams are characterised by a high notch detail, which weakens the support structure.

Figure 1: Support structure equipped with threaded bolts (left) and mounted pneumatic lines (right)

To overcome these disadvantages, press-bolts are available beside welded studs. Those bolts are applied by a process sequence based on cold forming [1, 2]. Figure 2 illustrates the process sequence in accordance to the bulletin DVS/EVB 3440-1 [3]. The press-bolt ② is insert into the carrier component ③. For this purpose, a stamp ① as well as a die ④ perform a cold forming process to fasten the press bolt in the sheet metal.

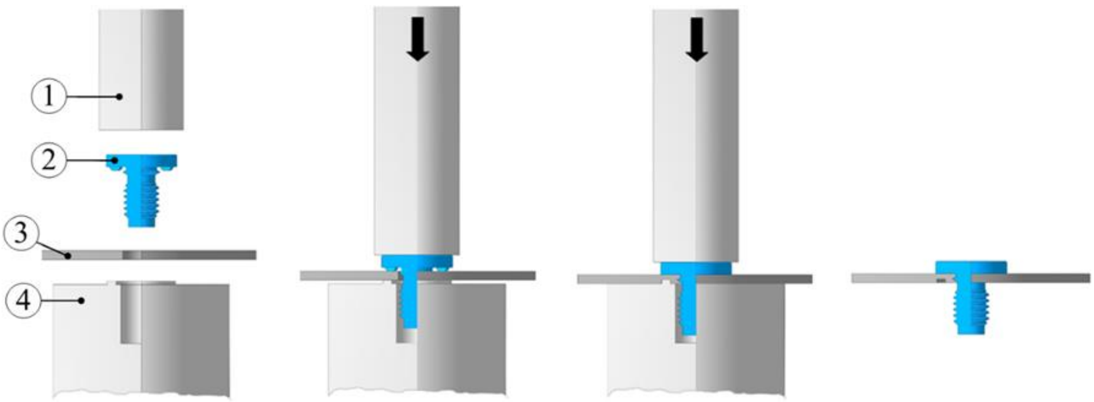


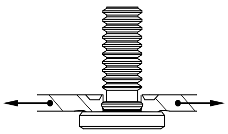
Figure 2: Process sequence for the application of press bolts according to DVS/EFB 3440-1 [3]

After the process sequence is finished, press-bolts enable the opportunity to join parts and components in sheet metal constructions. However, the insertion of these bolts applies a structural notch into the surrounding support structure. In respect to cyclic loaded constructions, such as railway vehicles, there is no knowledge about fatigue resistance now. Concepts of proof or design regulations, as they are commonly used for welded structures, are not available for such sheet metal sections.

The submitted study deals with fatigue resistance of metal sections formed by the insertion of press-bolts.

2 Methods

Looking at the example as shown in Figure 1, the structural notch of the formed sheet metal section must be considered in calculation of the fatigue resistance. Currently, there is no valid procedure to determine the fatigue resistance, either by numerical computation or experimental results. This lack of knowledge requires experimental investigations even if numerical calculations were also planned in the framework of this research project. The experimental investigations include cyclic tests with representative sheet metal and press-bolt diameter combinations. Table 1 displays the load-case and the bolt diameter as well as arrangement of the rotation feature beneath the bolt-head. The rotation feature is a specific constructive detail of the system which prevents the bolt from rotating in tightening the corresponding nut. Its constructive design depends on the manufacturer.

<table>
<tr><td>load case</td><td>A</td></tr>
<tr><td>schematic illustration</td><td></td></tr>
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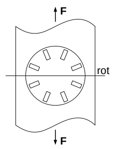
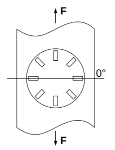
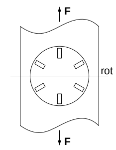
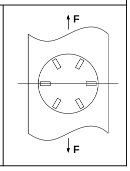
<table>
<tr><td>dimension</td><td colspan="4">M8 | M10</td></tr>
<tr><td>system</td><td colspan="2">I</td><td colspan="2">II</td></tr>
<tr><td>arrangement rotation feature</td><td></td><td></td><td></td><td></td></tr>
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Table 1: Load case and experimental plan cyclic testing

Additional, Figure 3 (left) displays the geometry of the test specimens. The specimens are designed in accordance to FKM project Nr. 198 [4] and SEP 1240-1 [5]. Three steels were selected as carrier sheet metals. The first one was a cold rolled CR1/CR2, low or micro alloyed stell with tensile strength R_m = 320 MPa and a sheet thickness of s_0 = 2.5 mm. The second one was an unalloyed steel for cold forming with R_m = 306 MPa and a thickness of s_0 = 1.0 mm. At last the third one was a construction steel S355, with a thickness of s_0 = 2.5 mm, which delivered a tensile strength of R_m = 510 MPa. On the right hand, Figure 3 shows the resonance test machine ZWICK/ROELL Typ HFP 5100 (S/N 12262628) for the fatigue studies. All fatigue investigations were performed with frequencies of 65…95 Hz, in a stress ratio of R = 0.1. The aim was not only to determine the range of time resistance, but also the endurance strength. Therefore, cyclic tests were carried out in accordance to DIN 50100:2016-12 [6]. The endurance strength was identified at a threshold of 2 million load cycles, whereby testing was also cancelled when a frequency deviation of 10 Hz caused by a beginning fracture was reached. Beside fatigue testing the first step requires static tension testing with the load case as displayed in Table 1.

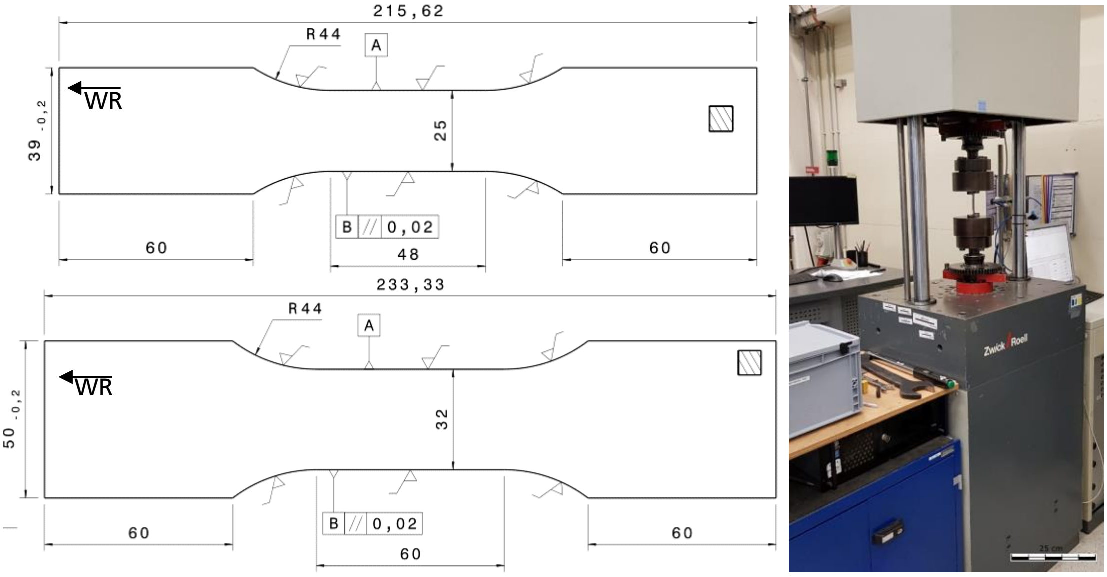

Figure 3: Geometry of the test specimen with press-bolts diameter M8 (left, top) and M10 (left bottom) plus test arrangement and machine ZWICK/ROELL HFP 100 (right)

3 Results

Initially, static load tests were performed to observe fracture modes and load-displacement-behaviours to compare the impact of different suppliers for press-bolts, of the types of sheet metals and of the orientations of the rotation features (Table 1). As assumed, the fracture occurs in the net-cross section area when applying a quasi-static transversal load. Figure 4 (left) illustrates the machine load-displacement-curves for both dimensions with the cold rolled sheet metal of 2.5 mm sheet thickness. The failure mode which consistently occurs under static load, independently from the tested configuration, is shown on the right hand of Figure 4.

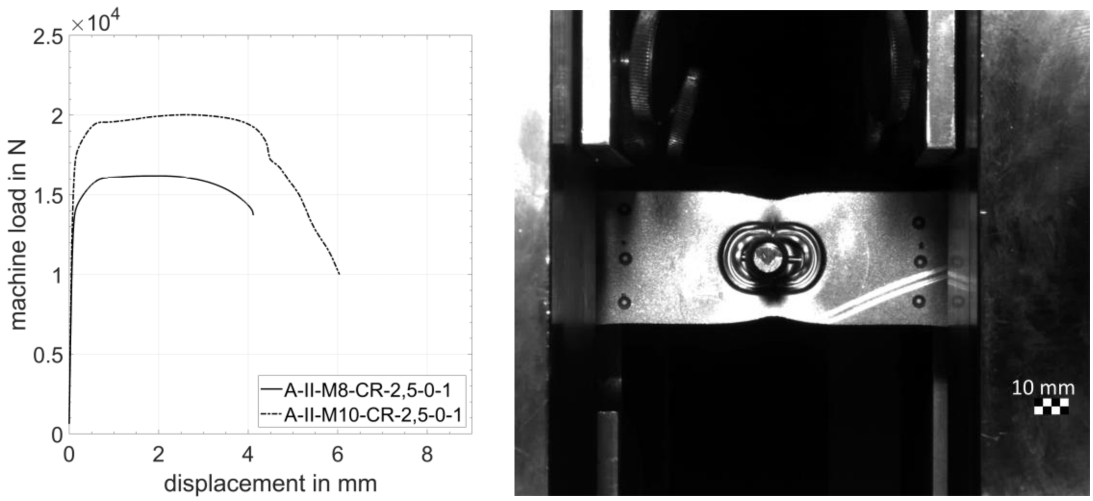

Figure 4: Load-displacement-behaviour for example of dimension M8 and M10 (left) and characteristic plasticisation in the net-cross section of the specimen (right)

Additionally, cyclic tests were performed in various combinations. As example Figure 5 delivers a comparison of press-bolts suppliers in dimension M8 for two different sheet metal tensile strengths. The investigated steel S355 with a tensile strength of R_m = 510 MPa is significant strengthen than the CR with R_m = 358 MPa. For welded joints like welded studs it is common knowledge, that raising steel strength does not affect in a higher fatigue resistance of the notch detail [7–9]. This behaviour is caused by the notch effect which eliminates the material strength in fatigue stress state. In Figure 5 the two press-bolt suppliers are represented by orange and blue colour.

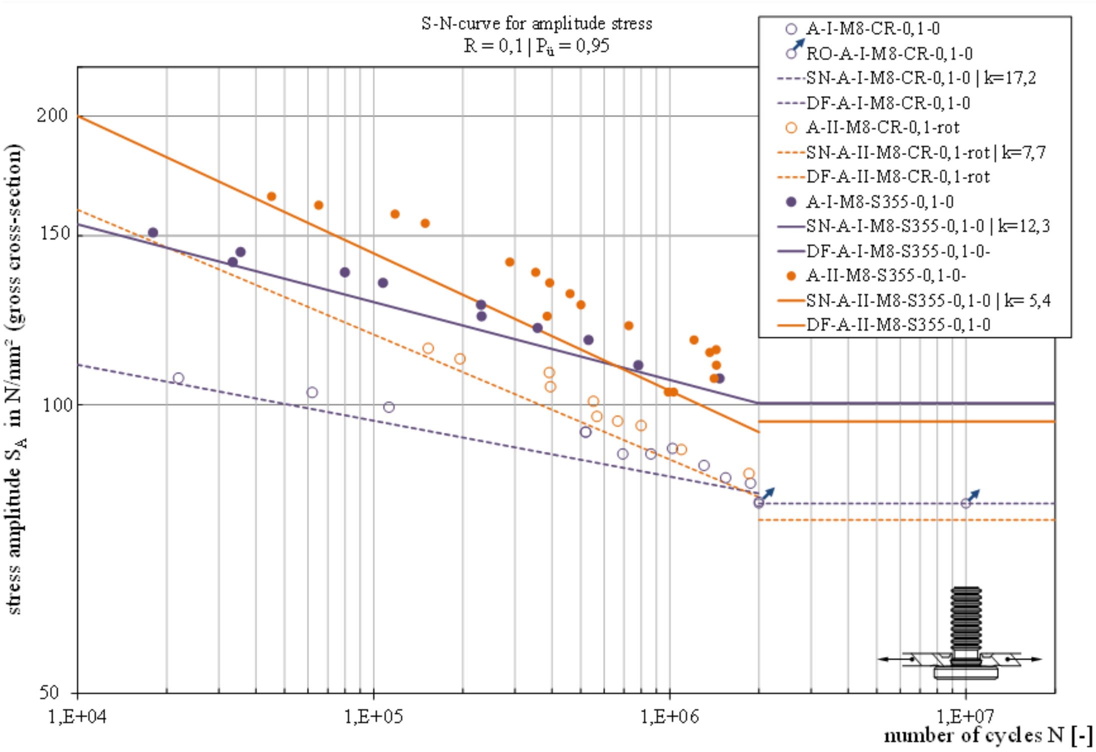

Figure 5: Results of selected cyclic tests in S-N-curve (WÖHLER chart)

The metal strengths in the chart are distinguished by filled and unfilled circles. All presented stress amplitudes SA as show refer to the gross cross-section of the specimens according to Figure 3. The configuration of the circles clearly pointed out that higher tensile strength leads to raising fatigue resistance. In the range of time resistance, the failure by fracture occurs on higher load horizons for the higher strength steel. Also, the endurance strength for the equal notch detail is situated on a higher level for the S355 sheet metal in the S-N-curve. This fatigue behaviour of press-bolts represents an additional advantage towards welded studs. However, it must be mentioned that the S-N-curve in Figure 5 should be evaluated with restrictions. Two different fracture mechanisms are hidden beyond the data points of the fracture event. Primarily, on higher stress horizons, a crack in the net cross-section occurs. When facing lower horizons, the cracking starts in front of or behind the press-bolt. As the research project is not entirely finished yet, the exact fracture pathway is still to be clarified. This includes the exact localization of the beginning, considering actual fractographic studies which are performed in scanning electron microscope.

4 Conclusions and Contributions

In the public founded research project AiF/IGF 20475BR press-bolts as functional elements are investigated, considering the insertion process by cold forming. The fatigue resistance of the support structure is essential for dimensioning and computation regarding the notch detail. Therefore, experimental as well as numerical investigations are performed to determine the resistance of formed sheet section as result of the cold forming process. This paper deals with the experimental studies which should provide fatigue data to expand the existing concepts of proof, especially the structural stress concept.

As conclusion of the static tensile tests, the rotation feature does not significantly affect to the load bearing capacity. In alignment with the static tests, it was also possible to confirm a bonded contact for the numerical load simulation by comparing experimental machine local load-displacement-curves with those of the numerical load simulation. Both results represent an enormous progress on the way to introducing a concept of proof for the fatigue resistance.

For the cyclic investigations it was proven that the crack initiation always occurs in the formed sheet metal section. Thereby two different fracture modes could be observed. The mechanism behind the fracture mode is still to be investigated. Moreover, it is demonstrated that cold formed press-bolt joints can at the same time obtain a high fatigue resistance and utilize their advantages as mentioned. The presented experimental studies will enable the opportunity to expand the local fatigue concepts by verification of the numerically determined values. Beside these conclusions, additional results from the comparison to welded studs, punched holes and different states of preloading on press-bolts deliver important knowledge for industrial applications in railway vehicles.

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