Fatigue testing of hot rolled strip for chassis components on component type specimens

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Abstract: To qualify materials for automotive applications and to be able to provide values for design and construction of parts and components, extensive investigations are necessary. Residual strain in components and the quality of the cutting edge are not regarded, when using standard specimens. Therefore, it is recommended to use a specimen, which is capable to simulate those influences. As a result of these considerations, a cup-type specimen was developed. The specimen is cut out of a sheet metal strip and formed according to specimens for Marciniak tests. This corresponds to forming processes in production with residual strains. After that, a hole is punched into the specimen to simulate cutting processes. The specimen is then tested under cyclic loading conditions; crack initiation and fracture of the specimen are recorded. Because the value for residual stresses and the quality of the cutting edge can be adjusted in this test setup, these production parameters can be detailed examined and different materials for chassis components can be compared. The paper will give an overview over the test-setup for testing the cup-type specimens, test parameters, methods for determination of cracking and recent testing results on hot rolled strip for chassis components.
Keywords: fatigue tests, component type specimens, hot rolled strip, chassis components

Introduction and motivation

The determination of mechanical properties of steel grades is one of the key processes of material suppliers. These mechanical properties are not only limited on tensile tests. Tests to characterise fatigue of materials are state of the art as well and were determined on a daily bases e.g. in Woehler tests or in tests determining cyclic stress-strain curves according to SEP1240. In addition, tests recording the forming properties were performed. It is obvious that extensive examinations are necessary to characterise steels. But, the values gained in these tests on raw materials are often not sufficient to evaluate the potential of steel grades in final components. Production-related influences on the material properties were not regarded.

Main influencing factors in manufacturing processes, for instance in producing chassis components, are forming and cutting. Residual strains, resulting from forming processes and the quality of cutting edges are mostly not regarded, when materials are characterised for these purposes.

Hot rolled strip is often used in chassis components. In these applications, the materials are pre-cut, formed and afterwards additionally cut. To be able to simulate these applications a specimen type was developed at SZMF, which will be named hereinafter cup-type specimen. The developed specimen is suitable to be tested under laboratory conditions on the one hand, and on the other hand is complex enough to examine the component related influences of manufacturing (Figure 1).

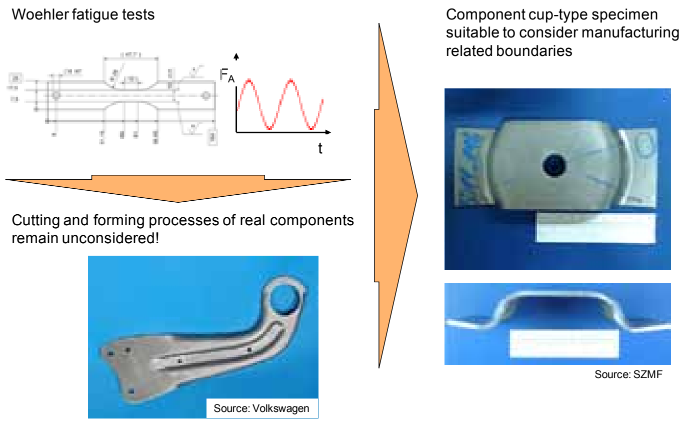
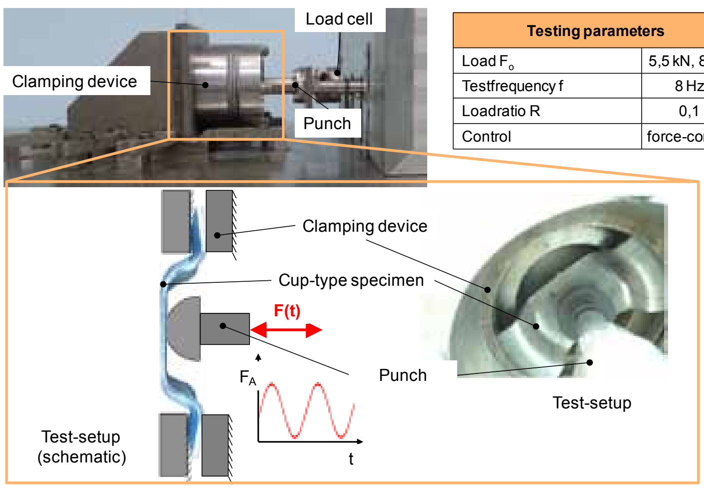


Figure 1: Motivation for development of specimens similar to components for characterisation of hot-rolled steel under cyclic loading

Test setup and test procedure

The cup-type specimen consists of a blank of steel sheet, which was formed into a cup. Afterwards, a hole is punched into the bottom of the cup. The specimen is fixed to the testing apparatus. A punch, which has a hemispherical shape, applies a controlled testing force to the cutting edges of the punched hole in the specimen, as shown in Figure 2.



Testing parameters	
Load F_o	5,5 kN, 8 kN
Testfrequency f	8 Hz
Loadratio R	0,1
Control	force-control

Figure 2: Test setup for cup-type specimens

The end of the test is defined as the complete fracture of the specimen. As the boundaries of the testing machine only allow testing with low testing frequencies, the tests are very time consuming. In addition, with this kind of test setup no information can be gathered, when cracks appear at the cutting edges of the cup-type specimen. But to be able to assess new steel grades and the influences of production boundaries, this knowledge is crucial.

This makes clear, why a method is needed, which is able to detect cracking as early as possible. In addition, it is advantageous, if the method for crack detection works in situ and can be used for ending the test.

Methods for crack detection

For crack detection thermometric methods and methods for determination of electrical conductance were used. Here, the tests were described, which were used to test suitability.

The methods for crack detection with thermometric temperature measurement are based on the physical principle of thermoelasticity. This principle says that every solid state body, which is mechanically loaded, responds with a reversible deformation, when loads are on the straight line by Hookes' law. One assumes that the load applied to a solid state body in his elastic region is saved completely as elastic energy and is released completely by resilience. The aforementioned effect does only occur on zero-defect materials. Materials in reality do always have small defects. The deformations in the area of these defects will often be plastic, even when deformations globally, that means for the work piece or component, will be elastic. In areas of these plastic deformations, the mechanical load will be partly dissipated.

In areas, where large areas of defects are allocated, more elastic energy will be dissipated as in areas, where fewer defects can be found. In addition, the friction of flanges of cracks in crack areas leads to a significant temperature rise.

A possibility to measure the rise of temperatures due to cracking is thermometric temperature measurement using thermocouples. This test setup was already approved in S/N-tests on joint specimens. Due to, in this case, punctiform joining elements, one has a simple to solve measuring task, as cracking can be defined as the local exceeding of a limit value. To perform such a measurement, not more than two thermocouples are necessary consisting of a measurement of a reference temperature and the measurement of the temperature of the joining element.

To implement this test-setup using a circumferential cutting edge of a punched part, it is necessary to place the thermocouples around the cutting edge in areas, where cracks occur with the highest probability. These areas are clearly identified in preliminary tests (Figure 3).

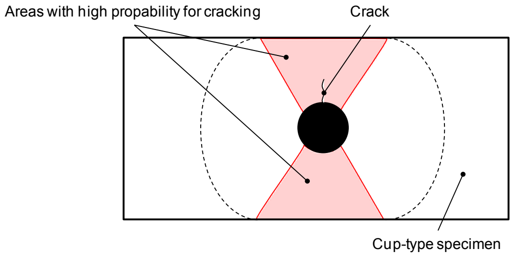


Figure 3: Areas of potential cracking

Cracking occurs in areas with the lowest cross section, starting at the cutting edge of the punched hole and proceeding in an angular range of 60 ° towards the edge of the specimen. Knowing this, following test setup was implemented (Figure 4).

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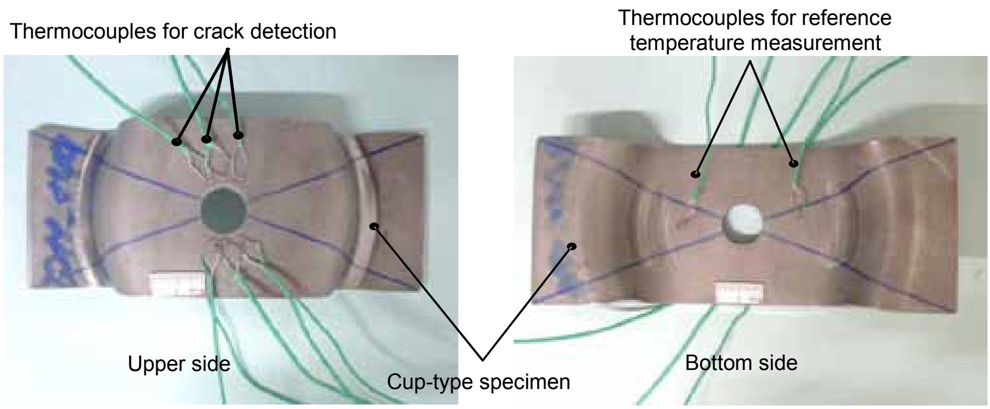

Figure 4: Test setup for thermo metrical determination of cracking

As thermocouples were welded to the specimen, it was appropriate to keep a certain distance to the punched hole in the middle of the specimen to avoid influencing the properties of the cutting edge due to warming during the welding process.
The thermocouple, which is nearest to the propagating crack in the area of the punched hole, measures the highest rise of temperature and is, therefore, used for determination of cracking.
Following figure shows a diagram with typical values, measured with the proposed test setup (Figure 5).

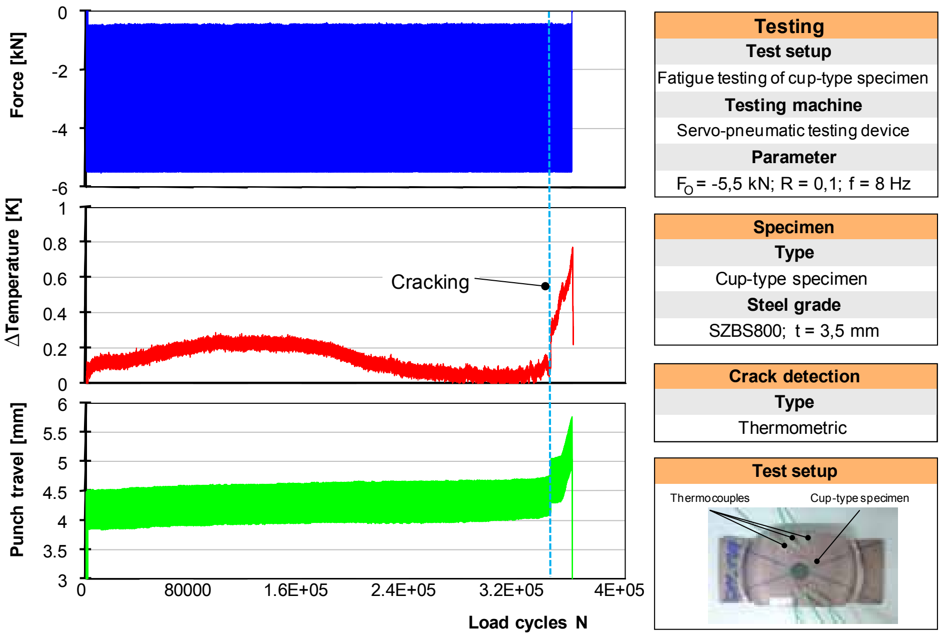

Figure 5: Woehler test of cup-specimen; crack detection using thermometry

The diagram displays the control variable force and the difference of temperature of the punched hole area and the unaffected material against load cycles. For control purposes, the plunger travel was measured, too. One can see that the measured temperature difference has a sinuous characteristic, which rises at first to a maximum and then lowers to a local minimum. As this rise of temperature only reaches 0.2 K it cannot be seen as significant in terms of cracking. After 340,000 load cycles, an abrupt rise in temperature can be realised. A comparison with the plunger travel shows that at this number of load cycles an abrupt rise of travel can be measured as well. It can be assumed that cracking starts at this time. Due to crack growth and friction between the flanges of the crack, the temperature rises until complete rupture of the specimens. The tests done for evaluation reasons show a similar behaviour so that this test setup is suitable, to determine the time of cracking. But it has to be said that it is difficult to define a test stop criterion by measuring the temperatures, as this value strongly depends on the position of the thermocouples and area of cracking. The specimen preparation is time consuming and the measuring instrumentation complex. To be able to characterise a large amount of specimens, for instance as a quality control instrument, this method seems not to be suitable.

Another method to detect cracking is the measurement of the electrical resistance or electrical conductivity of a conductor. Using this methods one can assume that a conductor without defects does not change its resistance or conductivity over test duration. If the conductor is damaged by cyclic loadings, the electrical resistance will rise and the conductivity will drop. This method for crack determination has been proven for years and is implemented in crack propagation gauges. A disadvantage of this method is that crack propagation gauges are only available for rectangular geometries, but not for 2d shape geometries as required for cup-type specimens. (Figure 6)

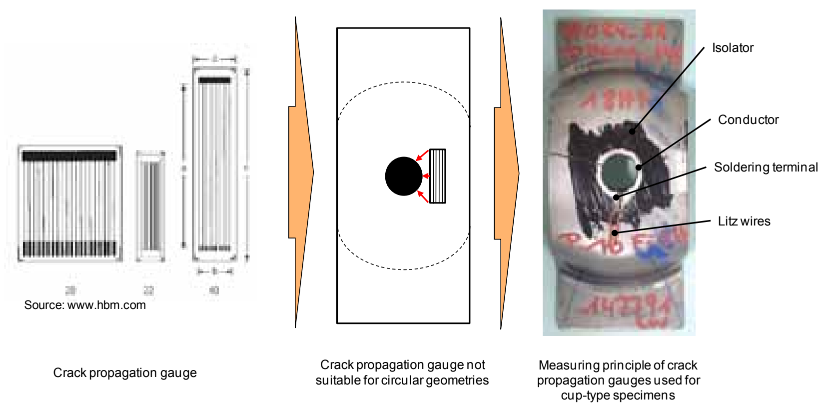

Figure 6: Crack propagation gauges and application of measuring principle for tests on cup-type specimens

To be able to use the measuring principle for crack propagation measurement on cup-type specimens, a brittle epoxy-coating was applied to the specimen. It is required that the epoxy coating is brittle enough to crack as well, when the coated material cracks in the area of the punched hole.

On this coating, a conductive lacquer coating is applied which is connected to the measurement equipment using a soldering terminal. During the tests, the conductivity of the conductive lacquer coating is measured continuously. To have a comparability of the results measured by this method, the measurements are standardised to one.

A result of a Woehler fatigue test, which was performed using this kind of measurement method, is displayed in Figure 7.
In this diagram, the testing force and the standardized conductivity are displayed against cyclic loadings. It can be seen that the conductivity of the conductive lacquer coating stays nearly constant over the first half of the test. At a value of cyclic loadings of 70,000 the conductivity starts to oscillate and finally drops to zero. At the same time, the plunger travel starts to rise so that one can assume that cracking starts at that time. Some tests were stopped directly after the conductivity dropped to zero. Examinations on these specimens show that already cracks appeared near to the surface, which did not run completely through the sheet metal. Concluding, it can be said that this method is suitable to detect cracking at a very early state. An automated stop of the test is easily possible. Due to the simple test setup and the reliably automated test stop, the proposed method was used to characterise hot-rolled steel for chassis components in Woehler fatigue tests.

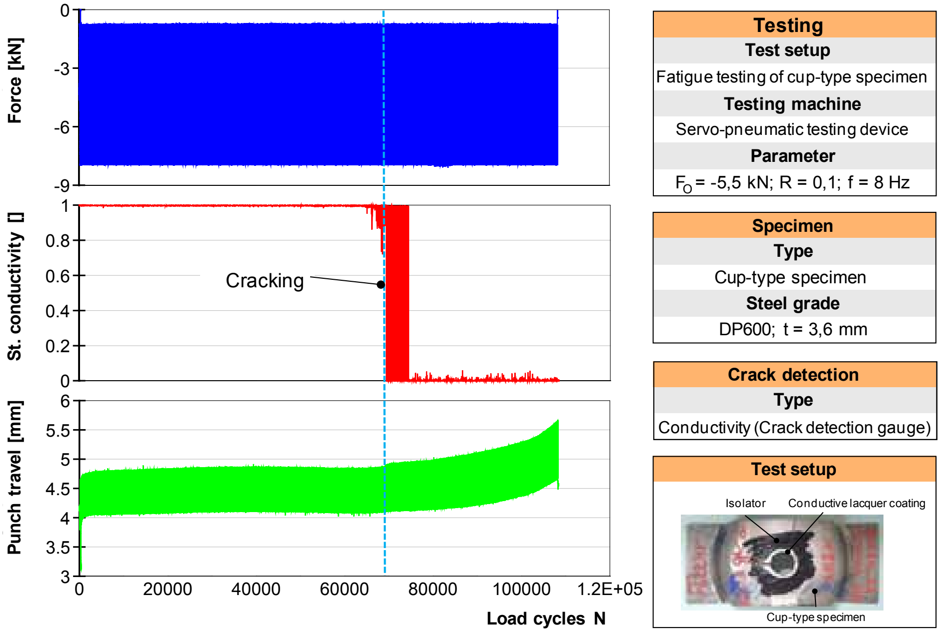

Figure 7: Woehler test of cup-type specimen; crack detection using measuring principle of crack propagation gauges

Determination of cracking Woehler curves on hot rolled strip using cup-type specimens

The tests were performed with a hot rolled strip grade SZBS800 in a sheet thickness of 3.5 mm. To simulate production influences on the results in cyclic Woehler tests, the die clearance and with it, the quality of the cutting edge were varied.

As an example, the results are displayed below, where the quality of the cutting edge is varied by the method of hole punching. Three batches of specimens were manufactured. In one specimen batch, the holes were drilled with a tolerance of 18H7. The other specimen batches were manufactured with a die clearance of 10 % tolerance and 30 % tolerance. The results are displayed below (Figure 8).

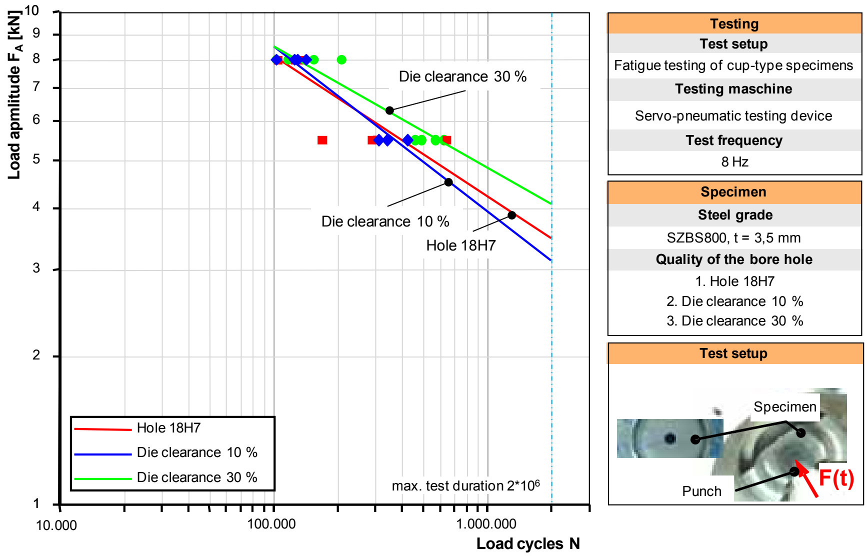

Figure 8: Woehler-diagram, cracking determined using crack propagation gauges, of SZBS800 - Influence of hole quality

It shows that increasing manufacturing tolerances, which were simulated by choice of the cutting parameters, do have influences on the load cycles until cracking appears. It can be seen that by using an idealised cutting edge (borehole, 18H7) cracking starts later as using a die clearance of 10 %. This is what can be expected, as the quality of the cutting edge decreases due to burrs. One can see as well, as the quality of the cutting edge decreases further, by using a die clearance of 30 % the cracking Woehler curve is shifted to higher load cycles. This effect could be explained by analysing the geometry of the cutting edges, hardness measurements and measurement of residual stresses. The results show that with increased die clearance, the quality of the cutting edges decreases due to burrs and inlets. But the results show, too, that residual compressive stresses are induced during the punching processes, which countervail the tension stresses during the tests. This means that the steel behaves beneficial under cyclic loads, even when the quality of the cutting edges degrades due to production related influences.

In addition, the developed test setup can be used to compare different steel grades. For this purpose, three different hot rolled strips were compared. As a production parameter, the specimens were cut with a die clearance tolerance of 30 %. The steels used are S355 (t = 3.6 mm), DP600 (t = 3.6 mm) and bainitic steel

SZBS800 (t = 3.5 mm). Figure 9 shows the cracking Woehler curves of the three tested materials.

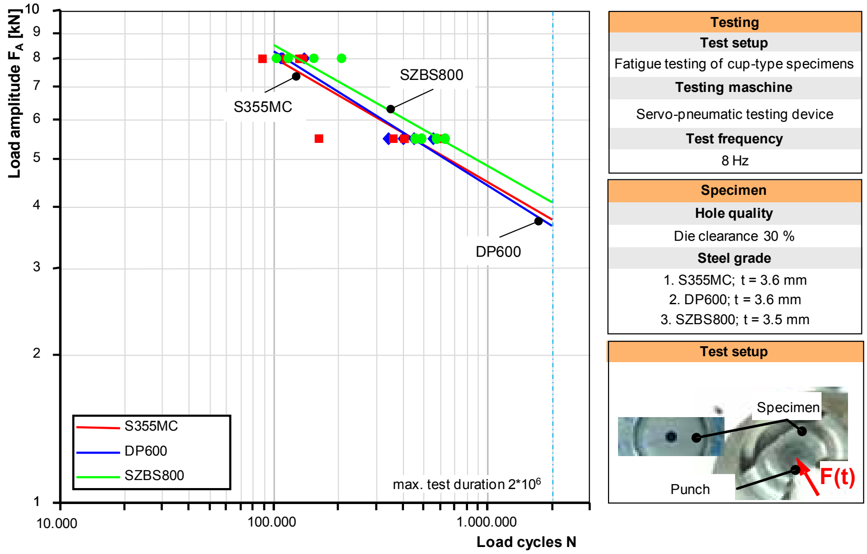

Figure 9: Woehler-diagram comparing hot-rolled steel grades S355, DP600 and SZBS800

One can see that the steels S355 and DP600 show a comparable behaviour. The Woehler curves are nearly identically, even the gradient of the curves is nearly the same. Compared to these well known steel-grades, SZBS800 shows a beneficial behaviour. Using the cup-type specimen, cracking starts using the bainitic steel with a shift of 200.000 load cycles.

Conclusion

It can be concluded that the chosen testing method, a customized crack determination gauge is most suitable for crack determination on cup-type specimens.
A comparison between conventional test stop at complete rupture of the specimen and the now used method of stopping using crack determination gauges show savings of 43 % in test time.
It can be concluded as well that using the cup-type specimen, production tolerances can be taken into account in fatigue tests, using a type of specimen, which is highly standardized, easy to manufacture and to test. The comparison of different steel grades, influenced with different production tolerances like forming operations and cutting, becomes possible and allows determining technological characteristics, which give information about the behaviour of steels which are closer to production processes than tests performed on material samples. The presented results show also, that the crack Woehler curve of SZBS800 is shifted to higher load cycles compared to conventional chassis steels S355 and DP600.
Results obtained with the cup-type specimens are highly suitable to compare different steel grades. In the future, the test setup will be further improved. In addition, results from the proposed test shall be made usable for fatigue strength calculations.