Local Reinforcements as Adjustments Reducing Imperfections

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Abstract. *Regarding load-adapted parts in transport vehicles, these components and devices should mostly perform the task of absorbing energy in case of a crash. The design of those crash relevant elements should meet demands e.g. the folding behavior and the crash energy absorption considering local imperfections due to cataphoretic drain holes or constructive conditions for welding operations in production processes. One possibility to assess the folding behavior of those parts is the crash test, e.g. in a drop impact tester. Nevertheless, regarding the essential equipment those crash tests are very complex and expensive. A simple and efficient alternative to test the folding behavior is the deformation testing under quasi-static preconditions.*

Keywords: *Sheet Metal Forming, Phase Transformation, Deformation Test*

1. INTRODUCTION

The testing of different load-adapted parts for crash relevant applications becomes increasingly important regarding the assessment of folding behaviour and energy absorption. Nevertheless, those crash tests are very expensive due to the necessary equipment [Behrens et al., Voges-Schwieger et al.]. A quasi-static deformation tester represents an inexpensive testing set-up for obtaining reliable information about parts and material.

At the Institute of Metal Forming and Metal-Forming Machines (IFUM), a quasi-static deformation tester was developed and realized in a hydraulic forming press. The folding and buckling behavior can thus be evaluated with less expensive equipment since a high-speed camera and the corresponding illumination level are not necessary. The deformation tester uses the punch in the hydraulic press as deformation inertia with various pressure forces and deformation paths. The investigated part is positioned on a self-adjusting calotte to ensure a vertical induction of forces or to adjust a concerted deformation angle. Below the calotte a load cell documents the force - distance - diagram. The deformation is recorded using a digital camera. Moreover, it is possible to discontinue the deformation test to document e.g. a special folding behavior from different positions. After that the test can be continued. By means of curve progressions, the formation of foldings or the continuation of the test can easily be determined in the force - distance - diagram. The developed deformation tester is a comparatively cheap alternative to a crash test at an earlier stage of part design and dimensioning.

The following results are dealing with different testing examples of welded double-U-profiles made of stainless steel and TRIP-steel. All tested specimens show a local increase in strength caused by additional forming elements which contain different amounts of strain-induced alpha'-martensite realized in a single deep drawing process.

2. QUASI-STATIC DEFORMATION TESTER

The development of a quasi-static deformation tester should fulfill the assessment of the buckling behaviour of load-adapted profiles. One motivation is the easy test set-up in comparison to the dynamic high-speed crash tests.

The deformation tester consists of an upper die for deformation and a lower moveable calotte with an integrated load-cell for the measurement of the local deformation force. Fig. 1 shows the developed quasi-static deformation tester, embedded in a hydraulic press.

By combining this deformation tool and the hydraulic press, a deformation tester with a path length of the press ram of about h_{st} = 500 mm and a pressure force ranging from F_D = 63 kN up to F_D = 630 kN can be realized. The deformation velocity is about v_D = 3.2 mm/s. With the presented test set-up, the forces necessary to deform the profiles can be applied and visualized. Moreover, it is possible to stop the test for a while to study the folding behavior from different points of view. The test can be continued after the stoppage, without risking a loss of test results. By stopping the test, a short slap in forces can be seen. This enables a concerted allocation of stopping the test in the force – distance – diagram.

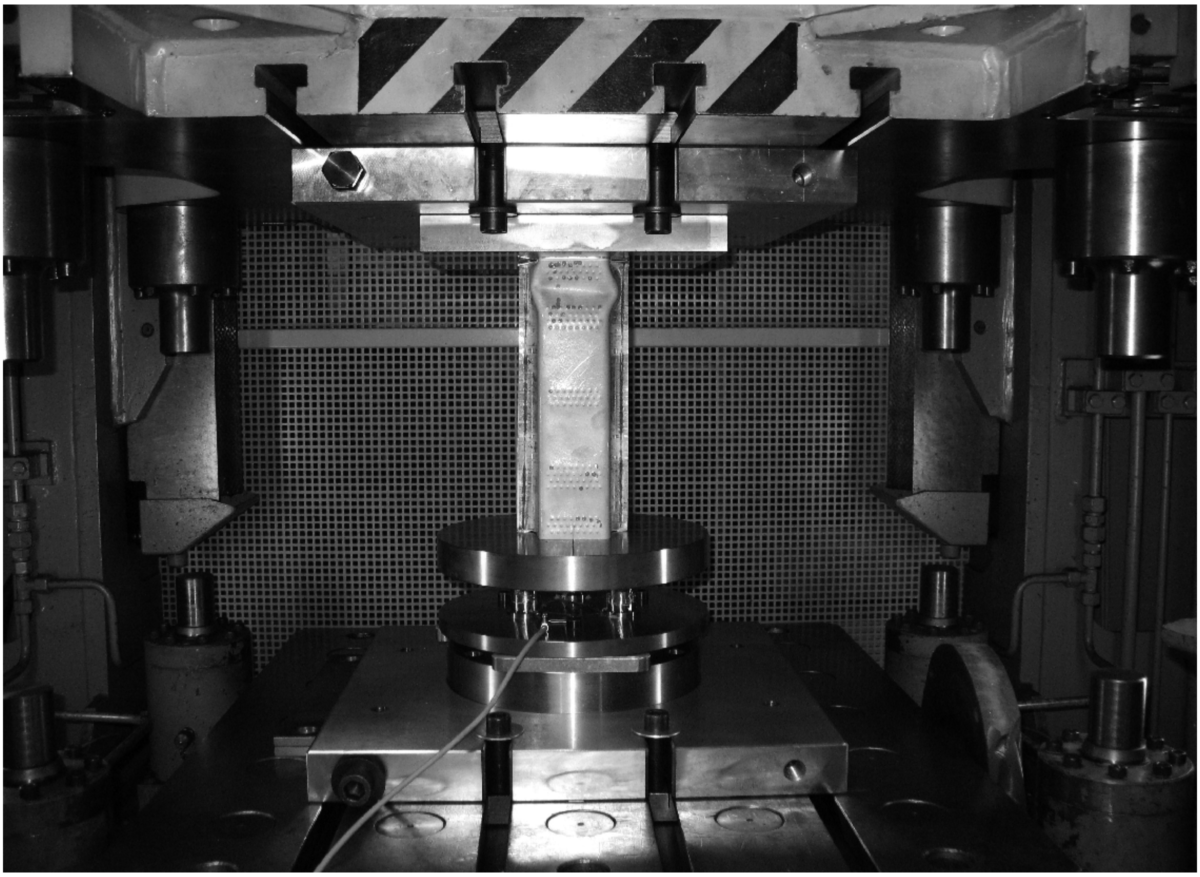

Figure 1. Developed deformation tester

2.1. Investigation of the deformation behavior.

The quasi-static deformation tests are carried-out in a hydraulic press. Therefore, two profiles were laser welded to a closed profile. Fig 2, left shows a double-U-profile made of the stainless steel EN 1.4301, investigated in these researches.

In the presented deformation tester, these profiles will be axially deformed. In regarding the deformation tests performed, the investigated profiles were made of the stainless steel EN 1.4301 and TRIP780. These parts show additional forming elements in round or oval geometries in concerted regions (Fig. 2, right). The analyzed parts show different alpha'-martensite contents due to different forming temperatures. Therefore, the effect on the deformation forces depending on differing martensite contents should be determined [Voges-Schwieger].

In comparison to standard high-speed crash tests, it is necessary to formulate individual criteria to stop the quasi-static deformation tests since during the deformation tests the load provided by the press is constant. Thus, a complete absorption of the load energy by the profiles is not possible.

Therefore, two criteria are formulated when to stop the quasi-static deformation tests. The first criterion considers a stop of the test after a distance of about s = 150 mm, which corresponds to the half of the profile height. It is assumed that after a deformation distance of 150 mm, a characteristic folding behavior is obvious. The second criterion to stop the test is a failure of the welded joint of the profile. No characteristic folding behavior will be achieved with a failure in this area. During the deformation test, the buckling behavior is documented by a digital camera.

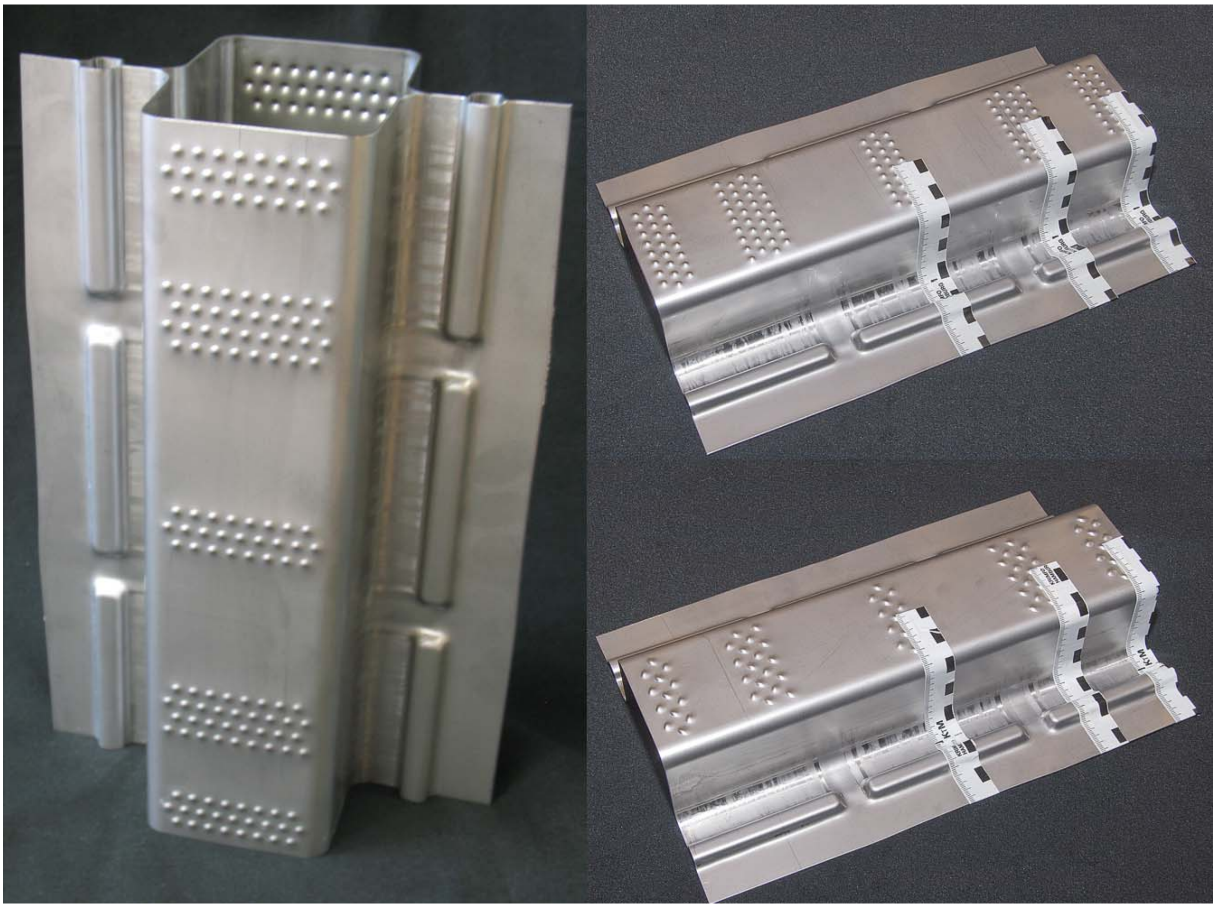

Figure 2. Double-U-profile (left) and U-profiles with round (top right) and oval additional forming geometries.

2.2. The deformation test

Regarding the documented folding behaviour it is obvious that the martensitic high-strength regions influence the buckling of the profiles. The deformation of the profiles takes reproducibly place between the structured areas of the additional forming elements. The force – distance - diagrams show three different force maxima. This is based upon the formation of three foldings. Fig. 3 shows these facts for a profile with round additional forming geometries made of the material TRIP780.

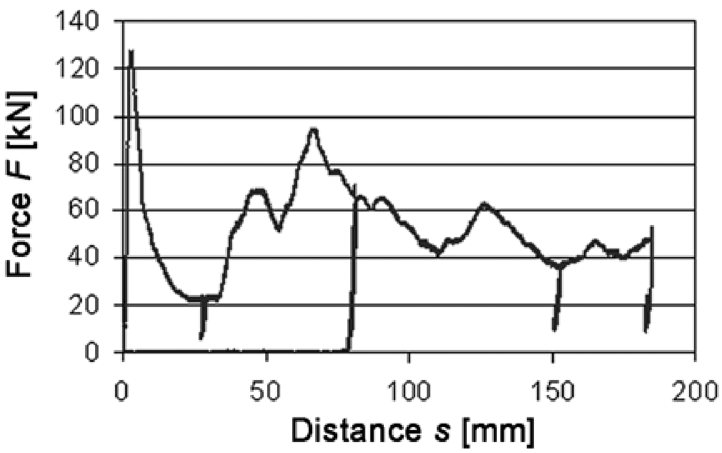

Figure 3. Force - distance - diagram of a quasi-static deformation test of a profile made of TRIP780 with round additional forming geometries.

The force maximum (trigger force) causes the first folding at the beginning of the deformation. The drop of the force after the first folding formation is based on the load relief at this stopping point. This leads to a temporary release of the profiles.

In Figure 4, the buckling behavior of the described profile made of TRIP780 is presented in chronological sequences.

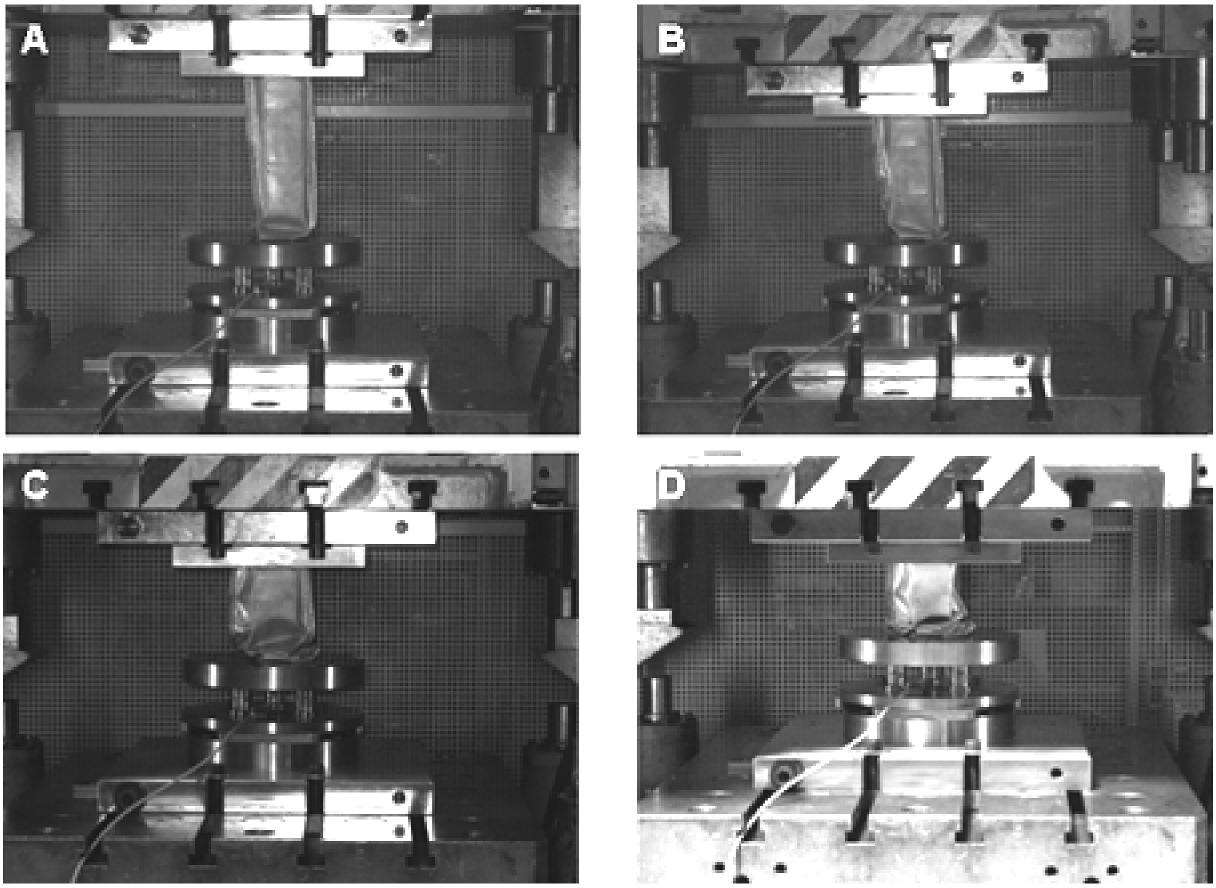

Figure 4. Buckling behaviour of a profile made of TRIP780 during the quasi-static deformation testing.

For the material TRIP780, the force – distance - progressions show higher maximum forces (F_{Max} = 140 kN) for oval alpha'-martensitic reinforcements than for round additional forming elements (F_{Max} = 130 kN). It is important to add, that both additional forming geometries show the same proportion.

In comparison to profiles made of the stainless steel EN 1.4301, higher maximum forces are determined at tested profiles with round reinforcements. The maximum force ranges are dispersing from about F_{Max} = 95 kN up to F_{Max} = 105 kN. The determined trigger forces for profiles with round reinforcements show reduced maximum forces of about 10 %. Moreover, round additional forming geometries could be determined to benefit a concerted formation of folding.

During the tests performed, an influence of different alpha'-martensite contents could be ascertained in consideration of the resulting deformation forces. A comparison between profiles with different alpha'-martensite contents for the material EN 1.4301 is illustrated in Fig. 5. On the left hand side, the force-distance-diagram is shown for a profile with a martensite content of $f^{\alpha'}$ = 16 % in the structures. On the right hand side, the profile shows a higher martensite content of $f^{\alpha'}$ = 22 % caused by a thermo-mechanical deep drawing process at lower temperatures of T = -20°C. This profile also shows distinctive maximum forces caused by the higher martensite content of the reinforcements.

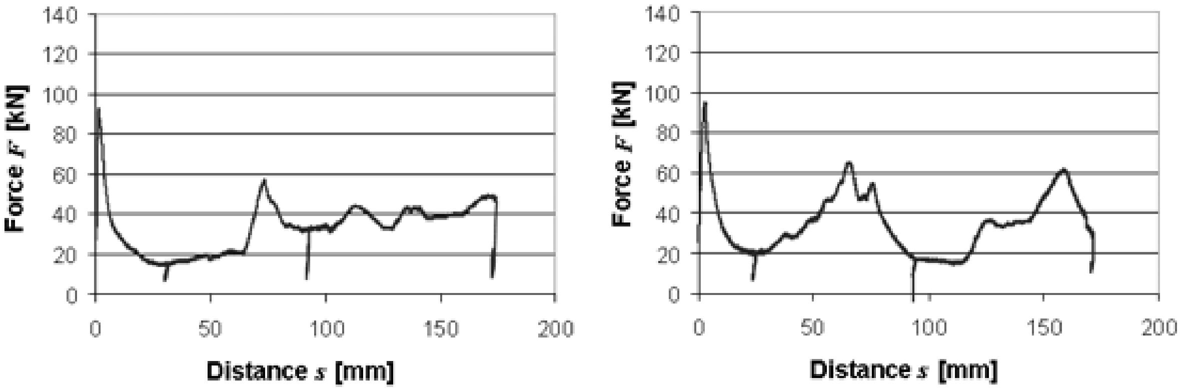

Figure 5. Force – distance - diagrams of a quasi-static deformation test of profiles made of EN 1.4301 with round additional forming geometries for martensite contents of about $f^{\alpha'}$ = 16 % (left) and martensite contents of $f^{\alpha'}$ = 22 % (right).

The comparison of the presented profiles shows higher trigger forces for the formation of the first folding for the TRIP780 profiles. Moreover, the deformation forces are increasing for the TRIP780 steel during the quasi-static deformation tests. It is assumed, that one reason for these effects is the high tensile strength of the TRIP780 material.

3. CONCLUSION

The quasi-static deformation test enables an assessment of the different effects of the profiles e.g. the influence of additional forming geometries, the material properties and the local alpha'-martensite contents. Moreover, the test provides a cheap and easy determination of the folding formation of different profiles for a first assessment of load-adapted parts. With the quasi-static deformation test it is possible to get an overview regarding the buckling behavior and the deformation forces. But it is no complete alternative for the standard high-speed crash tests. The quasi-static deformation tests cannot provide important crash information e.g. the deformation distance until a special amount of crash energy is fully absorbed.

Moreover, the investigations of round additional forming geometries for the stainless steel EN 1.4301 and the residual austenitic steel TRIP780 show a better folding behavior than for the oval geometries. Additional forming elements containing a higher content of alpha'-martensite show a higher characteristic of force progression. It can be assumed, that higher alpha'-martensitic contents in both investigated materials are leading to an increase in trigger forces and show a higher deformation force characteristic.

4. ACKNOWLEDGEMENTS

We would like to thank the Deutsche Forschungsgemeinschaft DFG (German Research Foundation) for funding the SFB 675 and the TFB 675. Sincere thanks to Outokumpu Finland, Tornio Works for providing different stainless steel grades.

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