Pre-stressed stringer sheets

Pre-stressing by forming of stringer sheet structures wrapped with FRP-straps

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Abstract

The pre-stressing of load-bearing structures offers many possibilities to influence their properties. In addition to an increased stiffness and strength, both the fatigue behaviour and the fatigue strength can be positively influenced. Although the principle of pre-stressing is used in many areas of technology to improve structures, this potential has not yet been exploited in load-bearing structures made of sheet metals. In the present project, it has therefore been investigated how sheet metal load-bearing structures can be joined and pre-stressed by forming using tendons made of fiber reinforced plastics and how such pre-stressing affects the load-bearing behavior.

Project description

The DFG-funded research project aimed at the investigation of the technological basis for the generation of hybrid load-bearing structures made of sheet metals and fiber reinforced plastics (FRP), whose stiffness and strength are optimized by means of stringers and a beneficial pre-stress by forming technology.

Figure 1 shows the mechanism used to join and pre-stress a stringer sheet structure with an FRP-strap. The stringer of the sheet metal structure is loosely wrapped by an FRP-strap. Subsequently, both components are formed together. The metallic component is elastically-plastically stretched, while the strap is elongated elastically. When the external load is released, the complete spring-back of the strap is prevented by the plastically elongated stringer, so that a pre-stressing force is generated. This force can be used to establish a frictional connection between the strap and the metal structure. The same force also creates of a favorable stress distribution in the sheet metal, which can counteract the stresses resulting from bending of the hybrid structure. Since FRPs, in contrast to sheet metals, have only a low ductility, plastically deformable coupling elements were developed in the project, which can deform instead of the FKV-strap and thus compensate for their low elasticity.

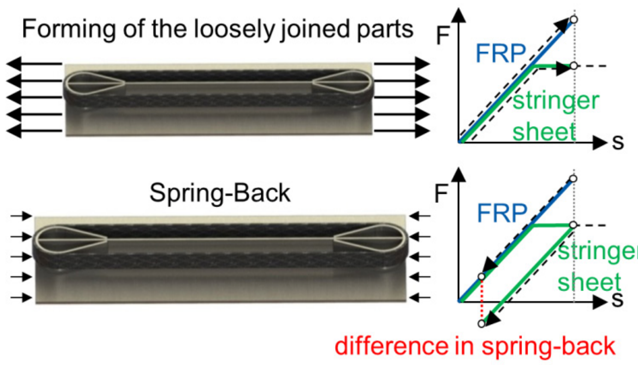
By means of characterization tests, analytical and numerical models as well as forming tests based on high-pressure sheet metal forming, the essential influencing parameters on the pre-stress were identified and design parameters for hybrid, pre-stressed stringer sheet structures were determined. In addition, the lightweight construction potential of the new technology with regard to the reinforcing and stiffening effect on sheet metal structures was examined more closely.

Results

The prestressing mechanism and the operation principle of the deformable coupling elements can be seen in Figure 2, using numerical and experimental tensile tests as examples. The diagram shows the forces transmitted by the stringer sheet and the FKV-strap as well as the plastic strains present in the coupling element over the total strain of the sample. It can be seen that the loop force initially increases linearly. With the beginning plastification of the coupling element, the increase takes on a smaller gradient. After the external loads have been released at the end of the test, it can finally be seen that the complete spring-back of the strap is prevented by the plastically stretched, metallic component and a permanent pre-stress is formed. The loop is loaded in tension, while the stringer sheet is subject to compressive forces.

Figure 3 shows the results of 3-point bending tests on a selection of specimens previously prestressed in tensile tests. The diagram on the left side illustrates the punch force-displacement curves for an unreinforced stringer sheet (grey) and three specimens reinforced with FRP-straps. It can be seen that the start of plastification as well as the bearable maximum forces can be considerably increased in the case of the reinforced samples. In relation to the respective sample mass, these are increases of approx. 34 % for the thin coupling element, 45 % for the thicker element and 1 % for the rigid element compared to the unreinforced reference sample.

The implementation of the joining and pre-stressing technology in a more complex geometry was carried out by means of high-pressure sheet metal forming as shown in Figure 4. Despite a low input of FRP-material, an increase in weight-specific strength against bending loads of up to 20 % was achieved in compression tests for the shell-structures produced in this way.



[1] Mechanismus des Fügens und Vorspannens hybrider Stegblechstrukturen

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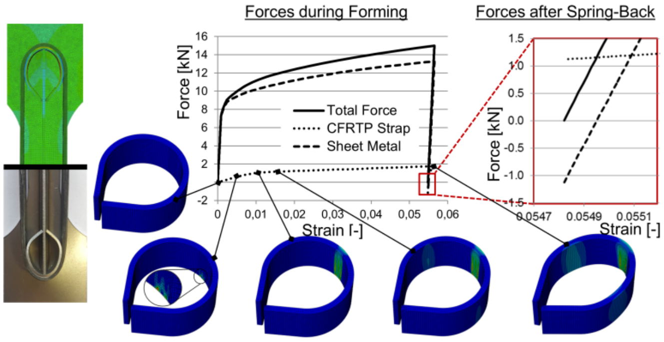
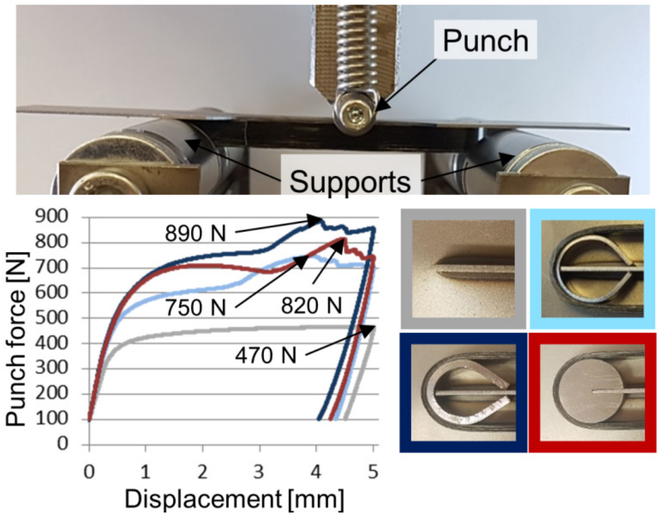
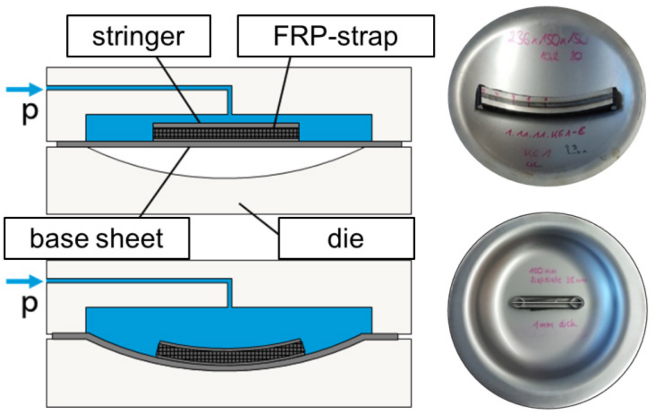


[2] Funktionsweise des plastisch deformierbaren Koppel-Elementes



[3] Verstärkungswirkung vorgespannter FKV-Schlaufen bei unterschiedlichen Koppel-Element-Arten



[4] Prozesstechnische Umsetzung der Vorspanntechnologie in der Hochdruck-Blechumformung (HBU)

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