HOLLOW LATERAL EXTRUSION OF TUBULAR BILLETS – A NEWLY DEVELOPED COLD FORGING PROCESS

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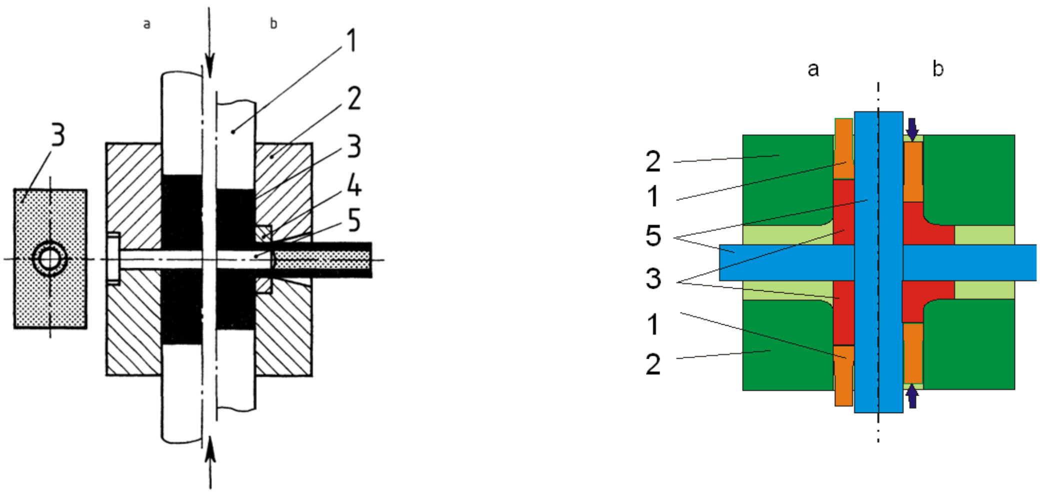
1 Abstract

Increased requirements in the automotive industry concerning reduction of CO_2 emission require the development of new solutions concerning this aim. Hollow components are particularly suitable for this goal, especially when dealing with rotating and constantly accelerated masses. Firstly, hollow parts contribute to vehicle weight reduction and secondly, the reduction of accelerated masses has an important participation to reduction of fuel consumption. Metal forming technologies in general - and especially bulk metal forming techniques - are suitable for the production of hollow construction units for the automotive industry, as they provide economical production from medium size to a large volume number of units.

In this paper, a newly developed bulk metal forming process – the hollow lateral extrusion process of tubular billets is discussed. This metal forming process is subject of a joint project between the Institute of Forming Technology and Lightweight Construction of TU Dortmund University and the Institute for Metal Forming Technology of the University of Stuttgart. Emphasis of this work lies on development of the forming process and the required tool concept. Thus, at first the process and its characteristics are introduced and forming part geometries producible by this process are explained. Afterwards, tool concepts for different kinds of part geometries are demonstrated. Following the objective of entire understanding of proposed forming process, numerical and experimental investigations of hollow lateral extrusion of tubular billets have been conducted. Finally, conclusions will be drawn concerning such newly developed cold forging process.

2 Introduction

At the Institute for Metal Forming Technology of the University of Stuttgart, a tool concept for the new cold forging process, “hollow lateral extrusion of tubular billets” was developed and installed. In standard DIN 8583-6, the hollow lateral extrusion process is described as follows: Lateral extrusion, whereby a branch with arbitrary hollow profile is extruded at a workpiece. The forming tool nozzle is thereby composed of a divided die and mandrel [1]. In this paper, a process is presented which uses a tubular billet in contradiction to the standard forming process described above. This requires radial support of the billet by an axial interior mandrel during the forming process. The process enables forming of hollow parts by cold extrusion with likewise hollow branches. Principle sketches of both process designs of hollow lateral extrusion are represented in Fig. 1.



a) b)

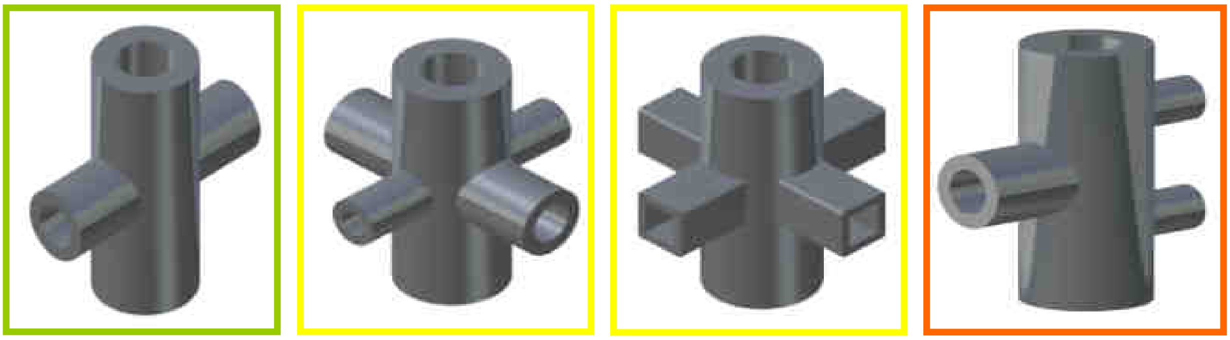
Figure 1: Principal sketch of a) hollow lateral extrusion and b) hollow lateral extrusion of tubular billets; the parts are named as follows: 1 punch, 2 die, 3 billet, 4 nozzle, 5 mandrel.

Fig. 1 a) shows hollow lateral extrusion as described in standard and Fig. 1 b) shows hollow lateral extrusion of tubular billets. The figures show the initial situation of the processes on the left side and the situation during forming on the right side. Some related processes and its characteristics are mentioned in specialist literature, so in [2] the production of a cog wheel hub is described. There, the last forming stage of the sequence of operations was lateral extrusion on the base of a tubular preformed billet. However, solid teeth were formed contrary to the process described herein. A problem of forming tubular billets was already mentioned in [2]: the development of folding due to the reduction of the surface at the internal area of the pressed part. Further examinations describe the lateral extrusion of a flange [3] on the base of tubular billets, or upsetting of flange on a hollow billet [4]. Special tools for lateral extrusion with additional forming tool shafts and for lateral cup extrusion are described in [5-9].

Ohashi et al. [10-12] described a process of lateral extrusion of pipes with a lost core of low melting alloy. At first the pipe section had to be filled up by low temperature melting alloy. This fill prevented the tube from collapsing during the lateral extrusion and had to be melted again after the forming process to get a hollow forming part. In this forming process the wall thickness of tube and branches are strongly connected to each other and it can be compared to tube hydro-forming.

3 Forming part geometries and tool concepts

Through the newly developed process, an expansion of the part family of cold forging is done as it enables cold extrusion of complex hollow geometries. A selection of component geometries which could be manufactured by the specified process is represented in Fig. 2. These part geometries can be classified in three degrees of complexity regarding the necessary tool technology. For forming of component geometries presented in Fig. 2 a – c) common equipment of lateral extrusion as closing die device and divided die can be used. The definition of the die division plane is done by centrelines of branches. Forming of hollow branches requires inner mandrels to ensure a defined forming process. Therefore, additional tool shafts are necessary to position, hold and eject such mandrels. The number of tool shafts required for component geometries represented in Fig. 2 a) and Fig. 2 b – c) led to a subdivision into different degrees of complexity. Because additional tool shafts are requisite for the forming of four hollow branches, the design of the transition area between branches and main body gets more complex. The tool design of hollow lateral extrusion gets even more complex if the centrelines of branches and the main body centreline have more than one intersection point. Therefore, an additional degree of complexity of tool design was defined. An example of such a forming part geometry is shown in Fig. 2 d).



a) b) c) d)

Figure 2: Forming part geometries of hollow lateral extrusion of tubular billets a) with two branches, b) with four branches and different kinds of, c) branches without rotational symmetry and d) branches with different intersection points of their axles.

For this purpose, the conventional equipment of lateral extrusion comprised of press machine and closing device can only be used conditionally. In this case, the division plane of the die is defined by the main body axis and centrelines of the branches. Machine and tool design for such complex forming parts could be similar to tube hydro forming. Closing travel and closing force could be generated by a simple hydro forming press. Kinematic functions relevant for this process, for example punch and branch mandrel motions, could be integrated in an installer tool, see Fig. 3. Two strong and position-controlled hydraulic cylinders could provide the forming force and the travel of punches. The positioning of the interior mandrels for forming the hollow branches would occur via additional tool shafts. These kinds of tool shafts could be driven electrically, pneumatically or hydraulically; depending on the force required for holding or rather ejecting the branch mandrels. Compared to the forming force, the force for ejecting branch mandrels would be low and these tool shafts could therefore be mounted modularly. The modular design could allow a different arrangement of mandrel tool shafts. Therefore the usage of the installer tool for different geometries of forming parts would be possible by using a new arrangement of mandrel tool shafts and an exchange of die and mandrels.

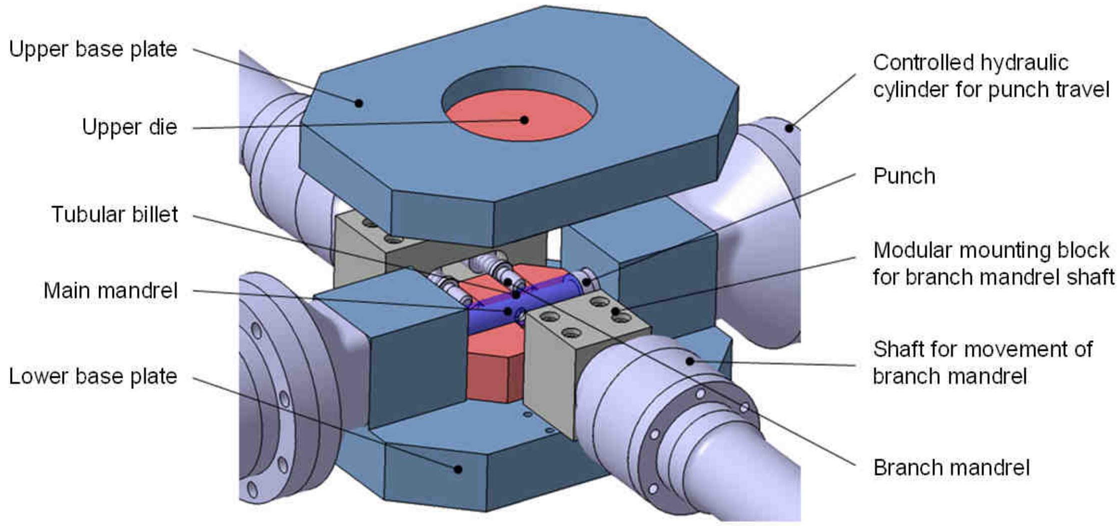


Figure 3: Concept of an installer tool for hollow lateral extrusion of forming parts with two or more intersection points of main body centreline and centrelines of branches.

4 Experimental setup

4.1 Forming part geometries

First fundamental investigations on the process hollow lateral extrusion of tubular billets were conducted with forming part geometry with two branches arranged perpendicular to the main body axis, represented in Fig. 2 a). The branches had a 180° alignment to each other and their centrelines had the same intersection point. This part geometry was selected for feasibility attempts due to simple tool design and symmetrical tool load. Restriction on two branches permitted a larger freedom of design of the transition area between the main mandrel and branch mandrels, than for instance with four branches. Besides, the tool load was obviously smaller using two branches at 180° alignment compared to a forming part with only one branch, because the material flow during forming is much more homogeneous.

For the investigations, the die container diameter was 30 mm and the outside diameters of the branches were 19 mm, the transition was chamfered at a radius of 1 mm. By changing punches, main-mandrel and branch-mandrel forming of different part shapes could be performed. First trials were done with diameter 20 mm of the main mandrel and a branch mandrels diameter of 12 mm.

4.2 Tool design

A hydraulic closing die device developed at the IFU was used as basis for the experimental setup. Two hydraulic cylinders pre-stressed by a nitrogen accumulator with 4 litres volume accomplished the cushion function for die closing and synchronous movement of the punches. An additional functional unit with tool shafts for the branch mandrels integrated into the closing device was used to realize the kinematics. Fig. 4 shows a principle sketch of the experimental setup in opened condition. The upper part of the forming tool was mounted to the press ram and the lower part onto the press table. The functional unit with additional tool shafts for the branch mandrels was installed at the lower clamping ring. Forming force is induced from the press table or rather the press ram into the billet by bush-like punches, which were supported on the pressure pieces and pillar pressure pieces.

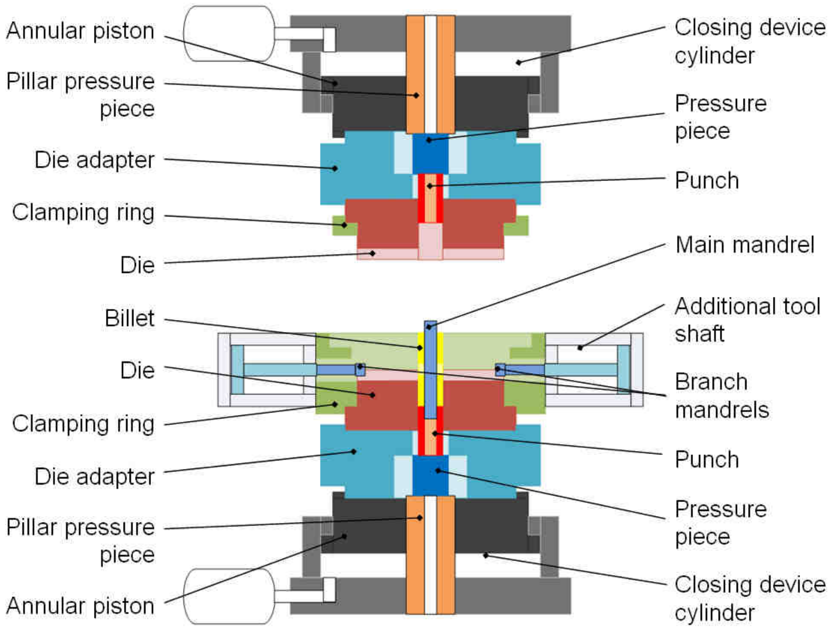


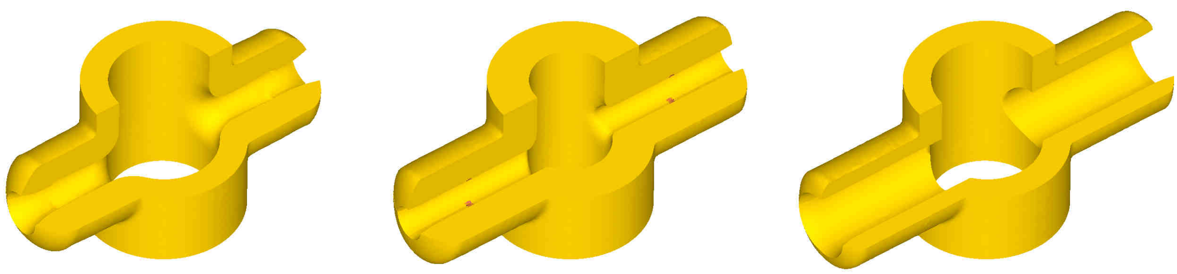
Figure 4: Principal sketch of the testing tool of hollow lateral extrusion of tubular billets.

For this special kind of lateral extrusion, a tubular billet was used and its inside was supported by the main mandrel. The tube was transverse punched, to allow positioning the branch mandrels on or rather in the main mandrel, which would be necessary for the forming process. High quality of the parallel-feed of the closing die device is required for the hollow lateral extrusion process. The synchronous movement of the upper and lower halves of the closing die device is particularly essential at the beginning of the forming; otherwise critical tool loads can be caused. Different process parameters could be recorded during the forming tests, which were in detail the travel of ram, upper and lower die, the lower punch force and the pressure of closing device cylinders.

5 Results and discussion

5.1 Results of finite element calculations

Finite Element analyses were carried out in cooperation with Institute of Forming Technology and Lightweight Construction of TU Dortmund University and results were provided. Studies of the material flow related to the variation of mandrels diameters showed different types of failure at forming parts. The outside diameter of the main body and branches was kept constant, while the main mandrel diameter was varied from 10 mm to 25 mm and the branch mandrel diameters from 6 mm to 15 mm. Results of these investigations are shown in Fig. 5.



a) Free formed branches b) Folding at branches c) Sound part

Figure 5: Results of finite element investigations: a) diameter of main mandrel 20 mm and branch mandrels 6 mm, b) diameter of main mandrel 15 mm and branch mandrels 6 mm and c) diameter of main mandrel 20 mm and branch mandrels 12 mm.

Unfilled branches occurred at combinations of thin walled billets and thick walled branches. In this case, the forming of branches was not defined by the tool nozzle because there was no respectively little contact between branches and die. The result of finite element analysis with main mandrel diameter 20 mm and branch mandrel diameters 6 mm is shown in Fig. 5 a). Folding at branches could be verified at forming part geometries with similar wall thickness of billet and branches, folds are marked red in Fig. 5 b. That folding occurred only at the beginning of the process. After the forming process changed into steady state, folding could be prevented. Most combinations led to forming of sound parts, especially if the nozzle cross section area was small or rather the billet cross section area was large.

Results of parameter variation concerning the mandrel diameters are summarized in chart in Fig. 6. Combinations marked in green colour led to forming of sound parts, while the red marked once led to failure parts with folding. Unfilled branches were formed with combinations marked yellow. The z-axis of the chart shows the specific punch force of the forming process. Considered was the punch force during steady state of the forming process referenced to the contact are of the punch. It could be observed, that the specific punch force rose with a low ratio of diameters at branches while the ratio of diameters at the billet had smaller influence on the specific punch force.

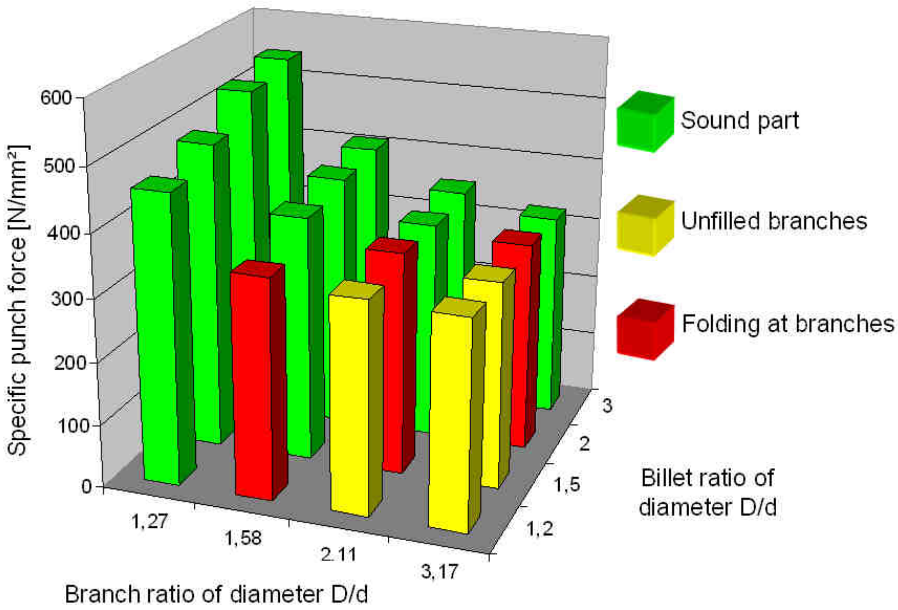
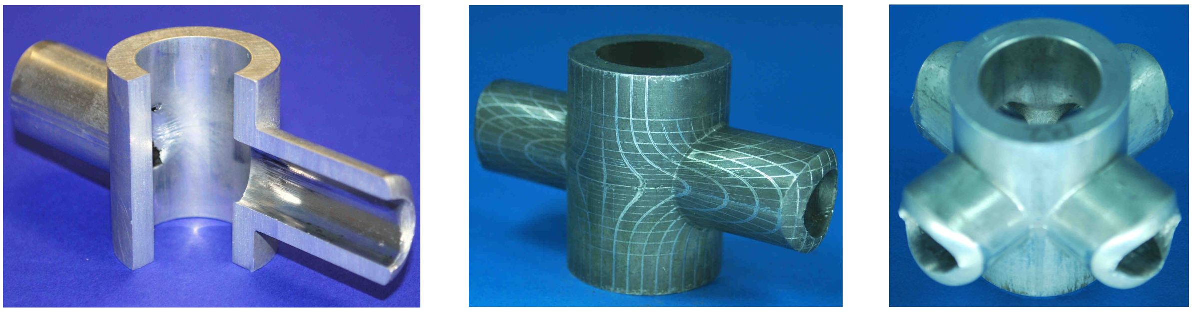


Figure 6: Specific punch force based on billet ratio of diameters and branch ratio of diameters.

5.2 Results of experimental investigations

Forming tests were carried out with the experimental setup described above and tubular billets machined out of bar material with an outside diameter of 29.8 mm and inside diameter of 20.2 mm. Additionally, the billets were transverse pierced with a cross hole (diameter 12.5 mm). As materials aluminium alloy EN AW-6060 and steel C4C were used. Aluminium billets were coated with zinc stearate and steel billets with phosphate and metal soap previous to the forming tests. Some results of experimental forming tests are shown in Fig. 7. The aluminium part in Fig. 7 a) was formed with a mandrel design, where branch mandrels had a rounded front surface with a corresponding radius as the mandrel of the billet; there was no penetration of the mandrels. This design permits small gaps between main mandrel and branch mandrels. The small formation of flash could not be prevented even at the maximum available holding force. Flash formation could be disabled by a mandrel design where branch mandrels were positioned in bags at the main mandrel. Figure 7 b) shows a forming part out of steel, where a square grid was applied on the surface previous to forming for visioplastic investigations. Displacement of grid intersection points demonstrated the local strain during the forming process. In Fig. 7 c), forming part with four branches is shown, where, at the inside of the part, folding could be observed.



a) Flash formation b) Visioplasticity c) Folding

Figure 7: Results of forming test of a) aluminium and b) steel with two branches and c) forming of four branches with aluminium.

Sensitivity to friction of hollow lateral extrusion of tubular billets is obvious due to the high ratio of contact surface compared to volume. Punch forces of simulations with different shear friction values and measured punch force of a typical forming test were evaluated for detection of a shear friction value via finite element analyses. The comparison of measured and calculated punch forces with different shear friction values for aluminium EN AW-6060 and forming of two branches is shown in Fig. 8. In simulations, the shear friction value m was varied from 0.06 to 0.18. Best fit of calculated and measured punch force curves was achieved by using shear friction value m = 0.12. The correlation between measured and calculated punch force is good, slight differences at the beginning can be attributed to the non-consideration of elastic behaviour in simulations.

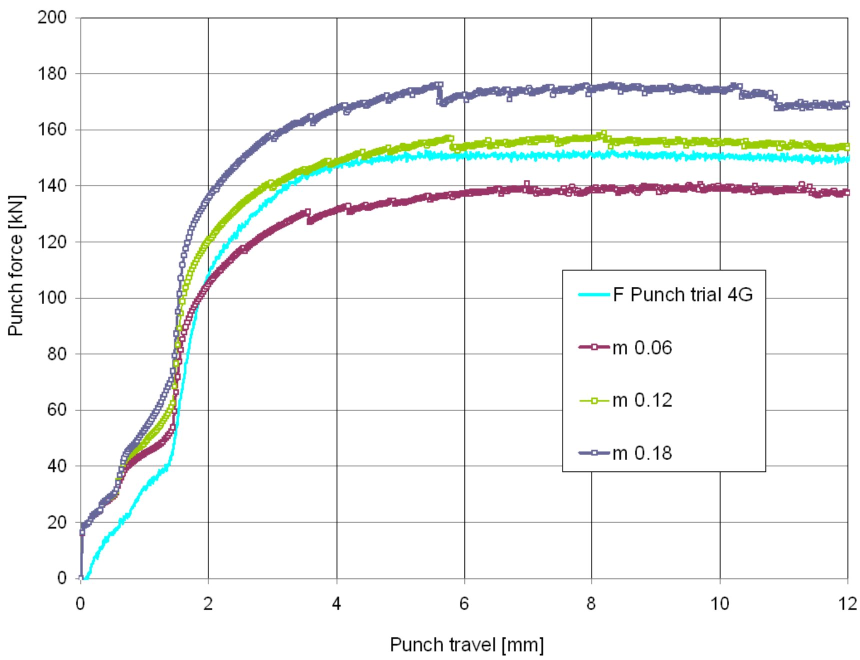


Figure 8: Comparison of measured and calculated punch force with different shear friction values m.

6 Conclusion

In the presented paper a new cold forging process “hollow lateral extrusion of tubular billets” was introduced. This process development expands the limits of cold forging concerning geometrically complex forming parts. Furthermore, the new kind of forming parts producible by this process were presented. Based on the investigations, the following conclusions could be drawn:

- For different part geometries tool concepts were developed.
- Different types of failure could be detected by finite element simulations.
- Forming of sound parts could be achieved with adequate ratio of billet and branch wall thickness.
- Hollow lateral extrusion of tubular billets is possible with aluminium and steel.
- The process is friction sensitive because of its high ratio of contact surface to volume.

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