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Bending of Extruded Profiles during Extrusion Process

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Abstract

Direct bending of extruded aluminium profiles during the extrusion process has numerous advantages in comparison to the conventional cold bending process. Since the workpiece is still warm during the bending process, the spring-back phenomenon can be avoided. Smaller bending radii can be produced in a single step. There are several basic differences among the existing methods. Some methods influence the material flow during the extrusion, so that a curved profile leaves the extrusion die. Other methods use a bending apparatus, which is placed directly behind the extrusion die. Based on the FEM-simulation results experimental investigations were performed on 8MN extrusion press.

1. Introduction

The role of aluminum in the construction of vehicles rose in the past few decades and it's utilization will still increase in the next years, as the technical progress demands lightweight construction to minimize energy consumption [1]. The application of curved aluminum profiles in the building of automobile bodies (space frame construction) and in the construction of railways vehicles are especially expected to further increase [2].

The semi-finished materials for the space frame structures in straight form are manufactured favorably by means of extrusion. A separate process step follows the stretch bending process to produce curved profiles [3,4]. The production of complex curved parts, which have hollow cross sections and flange (for attachment purposes etc.), is always connected with expensive tooling costs, since each cross section needs a set of bending dies [5].

Cross section deformation and profile twist, which sometimes accompany the bending process, lead to failure of the product. To reduce these failures, a special treatment of the workpiece is therefore necessary, e.g. a wrapping of the profile or the use of fillers for the production of bent hollow profiles [6].

Other production problems result from the spring-back of the bent profile. The amount of the spring-back is not precisely calculable, which means the required precision of the bending radius can not always be achieved by the over bending of the profile [7].

The productivity and quality losses of the conventional bending processes can be avoided in principle by using warm bending processes. Since the extruded workpiece is still at high temperature after the extrusion process, it will be favorable to bend the profile directly during the extrusion process. As an additional advantage the extrusion process and the bending process are able to be combined in one single manufacturing process.

2. Warm Bending Processes

The existing warm bending processes directly after the extrusion process can be divided into two groups. The first group influences the material flow of the extrusion material during the extrusion process, which can be achieved using three process variations. The first one influences the material flow in the deformation zone using a forming pocket, the second one influences the material flow before the deformation zone using an eccentric positioned mandrel and the third one influences the material flow after the deformation zone by varying the length and/or form of the bearing surface.

Extrusion using a die recess is applied if the continuous extrusion process is desired. This method reduces the dead time between each extrusion cycle, since the puller can work continuously too. Another advantage using a die recess is that the geometry of the die recess can be modified to make some correction in the material flow. Influencing the material flow intentionally to make a bent profile is also possible. The sides of the profile which exit slower are designed with a narrower die recess than the other side.

The friction between extrusion tools and workpiece can be exploited to modify the velocity distribution of the material flow during extrusion. In this case an eccentrically mounted extrusion mandrel induces an asymmetric friction in the extrusion billet, which causes an asymmetric velocity distribution during extrusion process. Due to this asymmetric velocity distribution bent profiles are obtained.

Due to the friction between container and billet during the direct extrusion a specific velocity distribution is obtained. In the center area of the billet the velocity reaches the maximum and decreases continuously until zero at the billet periphery. Extrusion dies with an eccentric die opening therefore allow a bent profile leave the die, although the velocity distribution of the material flow remains symmetric.

During the extrusion process the material flows in a specific velocity distribution along the profile cross section. Modifying velocities along the profile cross-section can be achieved by modification of the bearing geometry: a) Different length of the bearing surface, b) Different angles of inclination of the bearing surface and c) Different gap width of the inclination angle during production of hollow profiles.

The second group uses a bending device consisting of bending rolls, which are mounted directly behind the die or as usually done behind the counter platen of the press unit. In this process, 3D-bent and twisted profiles can be deformed using the heat from the extrusion process. The extruded profile is bent using a guide. The process is therefore divided into two steps, which is a great advantage for the simplicity of the process guiding. The first step produces the profile cross-section, the second step builds the bending contour. The bending contour is controllable over the entire extrusion process.

A modification of the above mentioned method is achieved using a segmented guiding device, or a serially placed guiding device. Each segment is controllable to provide the required bending contour. In this process, 3D-bent and twisted profiles can be obtained [8].

The bending contour is variable over the entire extrusion process. This idea is illustrated in Figure 1.

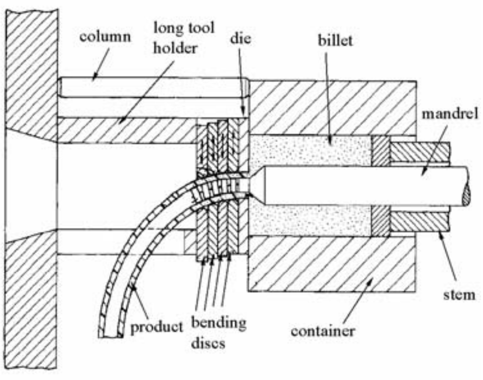

Figure 1: Bending process using segmented guiding device.

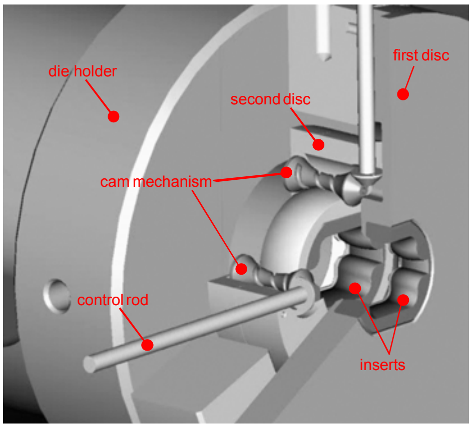

Figure 2: A cut of the bending device showing the inside elements.

In order to preserve a small bending radius the profile has to be able to leave the press before the counter platen. The extrusion die and the bending segments must be supported at some distance away from the counter platen and the supporting tool should have an opening to let the extruded bent profile leave the press without destroying the bending radius. Extrusion mandrel, which is applied if hollow profiles are extruded, is equipped by flexible extension to provide more stability.

The bending process according to the schematic in Figure 1 is realized in a bending apparatus, which is represented in the Figure 2. This bending tool consists of two bending discs with special inserts, which are made of graphite and changeable with other insert materials. The first disc is unmovable. It serves only as a fixture to define the beginning of the bending curvature. The second disc is moveable in two translation axis and one rotation axis, so that it has totally five degrees of freedom. The rotational movement of the inner part is controlled by two cam mechanisms through the control rods. If the cam rotates, the pin on the circumference of the inner part slides on the groove of the cam mechanisms, and the inner part is tilted. This bending tool is capable to produce a three dimensionally bent profile.

To simulate this bending process an Arbitrary Lagrangian Euler (ALE) FEM-code, PressForm ver. 1.4, was used. The bending device is modeled as a rigid sleeve. Different situations concerning the distance between the bending device and the die outlet from 0mm up to 55mm. Comparing the borderline cases in Figure 3 and 4 it can be concluded, that the product between the die and the bending device must be deformed, as the velocity differences near the bearing channel decreases continuously when the gap between die and device increases.

Although the guiding device is shifted 55mm (2.17 inch) away from the bearing channel the material flow still plays a role in the formation of the bending radius.

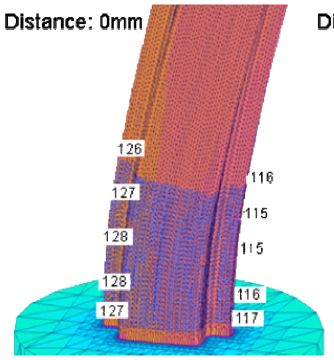

Figure 3: Bending using a fixed guidance

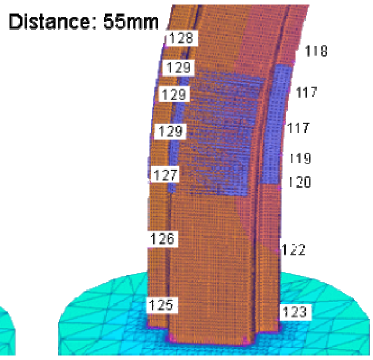

Figure 4: Guidance position 55 mm from the bearing channel

As aforementioned (cp. Figure 2) the bending device comes with two changeable inserts for the bending disks to reduce friction forces and to obtain the plate finish. To investigate the interrelationship between the friction inside the bending device and the geometry of the bended extrusion profile, computer-simulations have been carried out with varying values for the friction forces.

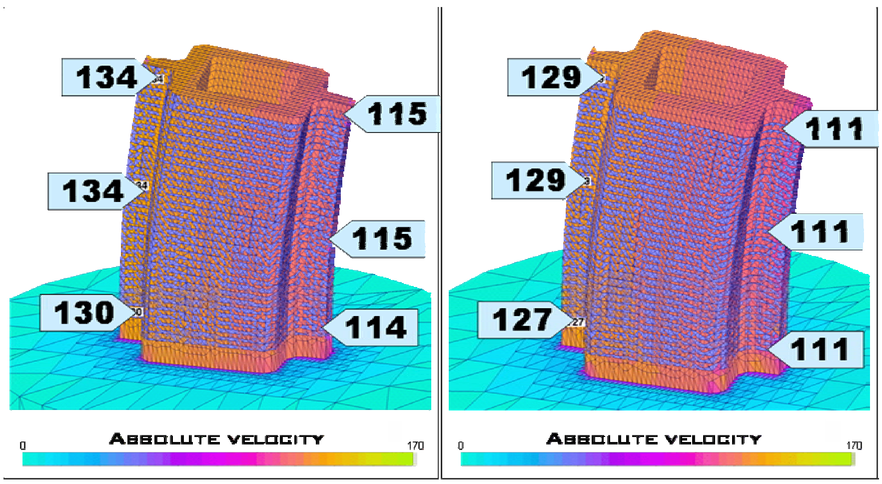

Figure 5: Bending with different friction forces caused by the bending device (left: 0,06 N/mm^2; right: 6 N/mm^2)

To reduce the friction factor between bending disc and extrusion product several inserts are tested with the objective of minimizing the required press capacity and preventing the product surface from damage. Therefore Al_2O_3- and TiBN-coated metal as well as graphite are used as insert materials (Figure 6) whereupon the solid graphite inserts have the favorable characteristics.

Figure 6: Bending disc inserts (left: Al_2O_3-coated metal, middle: TiBN-coated metal, right: solid graphite)

The trials were carried out on the 8 MN (800T) horizontal extrusion press of the R&D-Center of Extrusion at the Technical University Berlin.

Two tools configurations were tested during the trials to compare the results from the FEM-analyses. The first test for the first tools configuration was performed with a single unmovable bending disc. The bending radius was begun at the bearing channel. This test provided some hints about the friction between workpiece and guiding device as well as the bending load. The second test using the bending tool mentioned in Figure 2 provided an adjustable bending radius, which is not begun at the bearing channel but 55 mm away.

The microstructure of the bent profiles was investigated to see any changes occur due to the bending process. Generally there are no differences detected between the “as-extruded” product, which is bent on the bearing channel and the one bent 55 mm after the bearing channel. The samples were then annealed at 520°C for 1 hour.

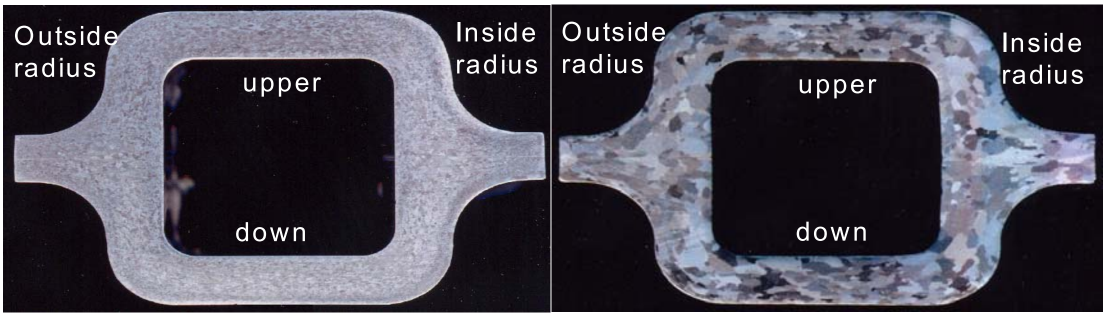

Figure 7: Microstructure of the profiles after the samples were annealed at 520°C.

The profiles, which are bent after 55 mm away from the bearing channel, show in its microstructure after the heat treatment coarse crystal grains (Figure 7 right), whereas the profiles, which are bent directly at the bearing channel, have still fine grains (Figure 7 left). The reason of the coarse graining is explainable from the remaining stress due to the additional hot deformation work during the bending process, which was released in the annealing process and caused the recrystallisation process. This led to crystal growth. A remarkable thing is observed during the analysis of the microstructure of the profile, which is bent directly at the bearing channel, that the flange corner at the inner side radius begins to develop coarse grains.

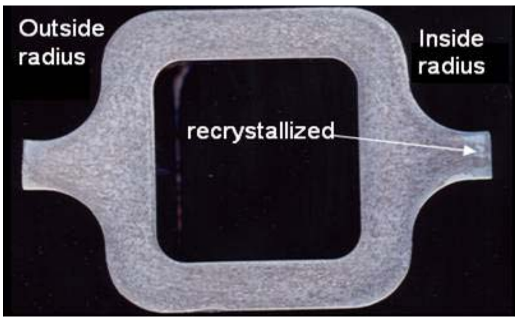

Figure 8: Microstructure with a recrystallized portion

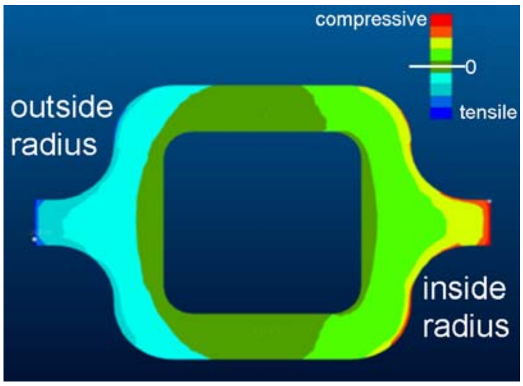

Figure 9: Stress distribution

Although the bending radius of 350 mm theoretically should not cause any non-linearity in his stress distribution, the microstructure reveals, that some remaining stresses in the inner wall radius exist, as at the flange corner coarse grains are seen (Figure 8).

For a better interpretation of the microstructure picture the stress distribution of a quasi-stationary profile is calculated by means FEM. An arbitrarily load and small bending radius are given in the calculation. The stress distribution in z-direction (perpendicular to the profile section) as the result of the bending force is represented in Figure 9. The cross section area, which undergoes a compression stress higher than 34 N/mm² (4931 psi), matches exactly with the recrystallized area of the microstructure picture (Figure 8).

3. Conclusions

From the investigation of the flow of material it is recognized that the bending procedure consists of two physical processes:
1. The formation of the bending radius by the out flow velocity difference
2. The formation of the bending radius by the deformation work

The formation of the bending radius by the outflow velocity difference occurs always first, as it needs less energy than the deformation work. The deformation portion increases, if the bending radius does not begin at the bearing face edge.
Therefore in order to get a better result bending radius should begin as close as possible to the bearing channel. To obtain a small bending radius the bending tool should also be installed as near as possible to the extrusion die. Bending a profile with a small bending radius has to deal with the non-linearity between the bending stresses and material flow.

The friction forces inside the bending device do not influence the outflow velocity difference and therefore not the desired radius but increase the strain within the bending fixture and the required press capacity. Friction forces can be reduced by using graphite inserts for the bending discs.

4. References

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