Influence of machining thin lightweight construction node components from aluminum alloys on residual stress and micro hardness in the outer surface zone

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Abstract

The described research work deals with the manufacturing of connection elements (Figure 1) made of Aluminum for the lightweight frame structure for the production of an electric car. The connection elements form the joining zones for tubular structures with a diameter of 40 mm. Joining processes for such as electromagnetic forming, welding or screwing are used. For these nodal structures to be light, but also adequate for the respective joining process, it is necessary to determine experimentally the minimum wall thickness of the nodal elements. For a weldment, the connection elements should have a similar wall thickness to the other part, while for electro-magnetic forming they should possess the highest possible rigidity. Furthermore it is necessary to identify the hardness changes and residual stresses in the outer surface layer brought about by the milling process as they influence the joining process [1]. For this reason these parameters are considered as boundary conditions for the determination of the minimum wall thickness.

1 Milling of the joining zones

At first the Aluminum stock is rough-milled to its approximate contour. Then through circular fine-milling with an allowance of 0.4 mm, the joining zones are made ready (Figure 1). Subsequently, a two-stage helical fine-milling is carried out for the formation of the final contour of the milling pocket using the parameters in Table 1, by side-milling with a torus milling cutter of diameter 16 mm.

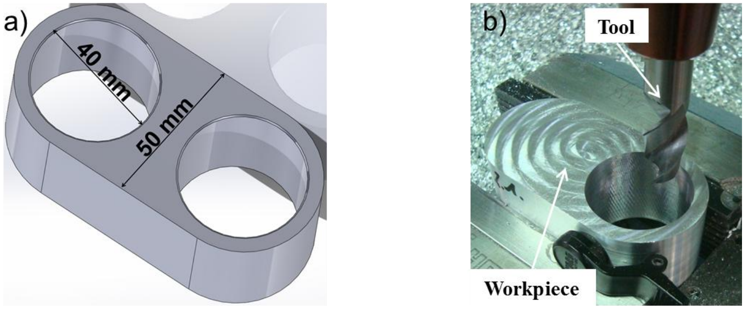

Figure 1: a) CAD model of the workpiece b) Workpiece after first roughing operation

Table 1: Process Parameters

Cutting speed v_c	500 m/min
Spindle speed n	10.000 min^{-1}
Feed per tooth f_z	0,05-0,1 mm
Axial depth of cut a_p	3 mm
Width of cut a_e	0,4 mm

As a part of the experimental trials, in addition to the analysis for the surface zone deterioration, insight into the minimum wall thickness should be obtained. Considering this background and using the same parameter combination, different workpieces with wall thickness lying in the region 1 mm $\leq$ b $\leq$ 5 mm were prepared.

2 Results of the micro-hardness and residual stress measurements for Aluminum EN AW-6082

For the estimation of the depth penetration of the surface zone after machining, hardness tests are first performed on the material in close proximity to the outer surface. Through the distortion of the molecular lattice as a result of machining, there occurs a hardness change in the superficial layers of the material with a steep hardness gradient [2]. The hardness of the workpiece before the milling process is 95 HV. Figure 2 shows an example of a hardness plot for the workpiece geometry with maximum wall thickness of 5 mm.

By performing micro-hardness tests after the finish milling process only a light hardening in the outer border region was detected. The increase of the hardness value near the superficial surface was only about 15 HV. After a depth greater than 0.5 mm the hardness reached its value of 90 HV again.

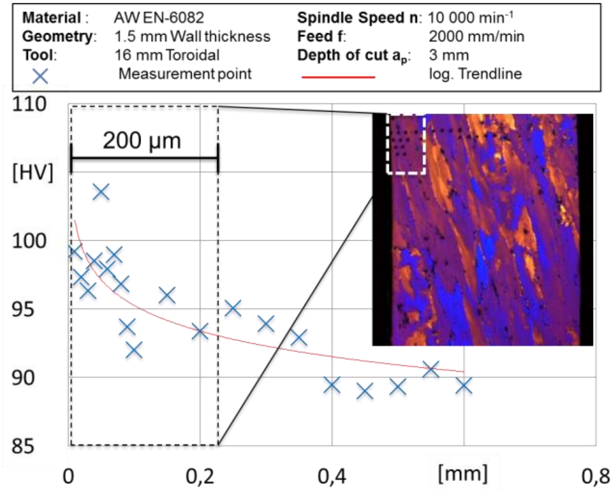

Figure 2: Results of the micro-hardness measurement of the workpiece with the minimum wall thickness of 1.5 mm

For the determination of the residual stress state in the outer surface zone, measurements for the purpose of this work were carried out with the help of the hole drilling procedure. The measurements were carried out on a high speed circular milling machine. Therefore, for every vertical step Δ two principal stresses σ1 and σ2 were determined by strain gauges. There are residual stresses having 90° offset directional vectors which span a plane parallel to the theoretical surface of the workpiece (plane stress) [3]. Figure 3 shows an example of a profile of the residual stresses for a workpiece having a wall thickness of 1.5 mm. It is to be noted here that there is a sharp increase in stresses above a depth of 0.2 mm. When processing components with lower wall thickness, the outer processing has also influence on the residual stresses. Therefore, a wall thickness of 1 mm is not sufficient. Further investigations proved that the minimum wall thickness is 1.5 mm.

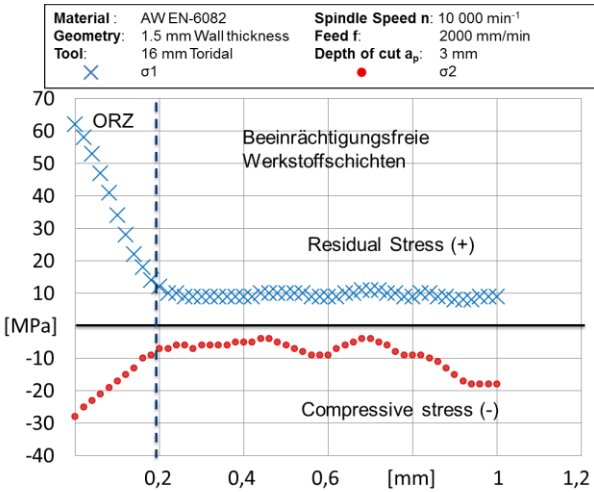

Figure 3: Results of the residual stress measurement of the workpiece with the minimum wall thickness of 1.5 mm

Summary

To realize the manufacturing of the nodal elements with a maximum reduction of weight and a minimal use of resources, the minimum wall thickness of 1.5 mm was identified. Compared to the previous nodal elements there, a significant weight reduction was achieved. The residual stresses and hardness changes can now be specifically introduced in the component based on the targeted joining process.

References:

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