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Fine Blanking Limits of Manganese-Boron-Steel in Fine Blanking Compared to Tempered Steel with Variation of Sheet Metal Temperature

Ingo Felix Weiser[1,a*], Tim Herrig[1,2,b], and Thomas Bergs[1,2,c]

[1]Laboratory for Machine Tools and Production Engineering (WZL) of RWTH Aachen University, Campus-Boulevard 30, 52074 Aachen, Germany

[2]Fraunhofer Institute for Production Technology IPT, Steinbachstr. 17, 52074 Aachen, Germany

[a] f.weiser@wzl.rwth-aachen.de, [b]t.herrig@wzl.rwth-aachen.de, [c]t.bergs@wzl.rwth-aachen.de

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Abstract. Fine blanking is a key technology for the near-net-shape production of sheet metal components. It is often used in combination with processes such as deep drawing. With increasing environmental requirements, the processing of materials with lightweight construction potential is becoming more and more important. A group of materials with high potential for lightweight construction, not only due to their suitability for hot stamping, is the group of manganese-boron steels. The fine blanking properties of these steels have not yet been exhaustively investigated. In this work, the fine blanking properties of the manganese-boron steel 40MnB4 were investigated in comparison to the quenched and tempered steel 42CrMo4. This was done using a star-piece fine blanking layout with investigation of die roll as well as tooth tip cracking. Furthermore, an investigation of the high-temperature fine blanking properties were investigated by means of inductive heating prior to fine blanking. The process forces were evaluated depending on the sheet metal temperature. A good fine blanking capability of 40MnB4 could be confirmed. Process forces and product quality were comparable to 42CrMo4 steel. Accordingly, an industrial application of fine blanking to manganese-boron steels seems highly promising.

Initial Situation and Motivation

To mitigate the effects of climate change, it is necessary to reduce emissions of greenhouse gases such as CO_2 [1]. The industrial sector is the second largest source of emissions in Germany, accounting for 21% of total emissions. A large and in recent years increasing share of this 21% comes from the iron, steel and non-ferrous metal industry. In addition, the transport sector is the third largest source of emissions with a share of 17.7%. Road traffic accounts for 96% of these emissions [2]. Taking the transport sector and the automotive industry in particular as an example, a change toward electromobility and fuel cell use is currently becoming apparent. As a result, vehicle weight is increasing: alternatively powered hybrid and battery vehicles regularly have an additional drive-related weight of up to 250 kg [3]. Consequently, the fine blanking industry will face a slightly diminishing market with growing lightweight construction requirements. Thus, the processing of new steel groups with lightweight construction potential becomes imperative also for fine blanking, which is a productive and highly accurate manufacturing process [4].

Scientific Problem

In combination with hot stamping, manganese-boron steels have been subject of investigations. E.g. *Nothaft* [5] found out that shear cutting is possible after hot stamping. This fact notwithstanding, *Hoff* [6] proposed to provide locally softened areas for punching and trimming, for which tailor-made blanks in particular are apt. *So et al*. [7] investigated the process combination hot stamping and shear cutting of 22MnB5 (material number 1.5528). One of the first investigations of fine blanking of manganese-boron steels was published by *Weiser* in German language in 2021 [8]. Some of the results published there have been taken up again for the present publication. A scientific investigation of fine

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blanking of manganese-boron steels with comparision of the process forces with standard fine blanking steels such as 42CrMo4 (1.7225) is, however, still lacking. The present publication aims at closing this gap.
According to *Naderi* [9], 37MnB4 (1.5524) is the manganese-boron steel best suited for highly stressed components among the ones he studied. Due to its very similar properties, but even increased strength, the manganese-boron steel 40MnB4 (1.5527) is investigated below.

Approach

The investigations are carried out on steel sheets made of 40MnB4 (1.5527). These were provided by thyssenkrupp Hohenlimburg GmbH and are available there under the name precidur HLB42 [10]. Table 1 shows the elemental composition of the steel from the melt analysis, which was confirmed at the WZL by means of spark spectroscopy analysis.

Table 1: Chemical composition of the 40MnB4 specimens in mass %

Chemical Composition	**C**	**Si**	**Mn**	**P**	**S**	**Al**	**Cr**
Melt Analysis	0.42	0.26	0.83	0.013	0.002	0.043	0.32
Spark Spectroscopy	0.404	0.270	0.876	0.0173	0.0055	0.0413	0.302
Chemical Composition	**Cu**	**V**	**N**	**Ni**	**Mo**	**Ti**	**B**
Melt Analysis	0.03	0.003	0.0061	0.04	0.01	0.020	0.0010
Spark Spectroscopy	0.0328	0.0036	0.0134	0.0396	0.0135	0.0369	0.0017

The use of 40MnB4 steel ensures that one of the most promising steels from the manganese-boron class is used for the fine blanking tests. The tensile strength in the annealed condition is up to $R_m = 610$ MPa [10] and thus comparable to the tensile strength of 42CrMo4, which is up to $R_m = 640$ MPa in annealed condition [11]. Micrographs of this steel are shown in Figure *1*.

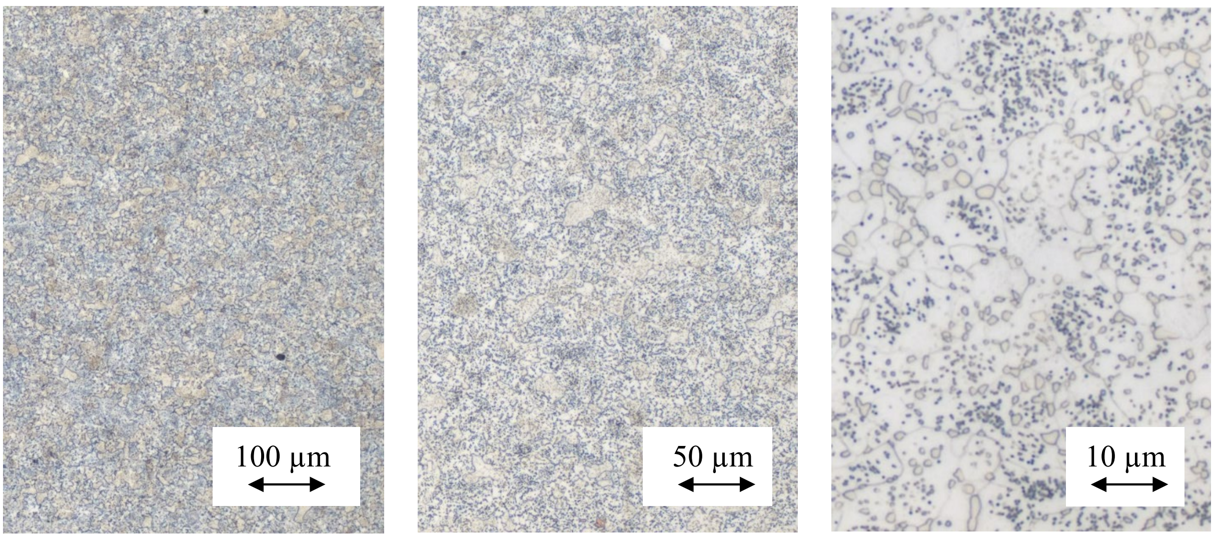

Figure 1: Micrographs of 40MnB4, different magnifications

As can be seen in Figure *1*, the specimens show regular, homogeneous perlitic-ferritic microstructure. For the basic investigation of fine blanking capability, a cutting layout corresponding to a star part was chosen. This reference geometry was inspired by the company SSAB [12] and can be seen in Figure *2*a).

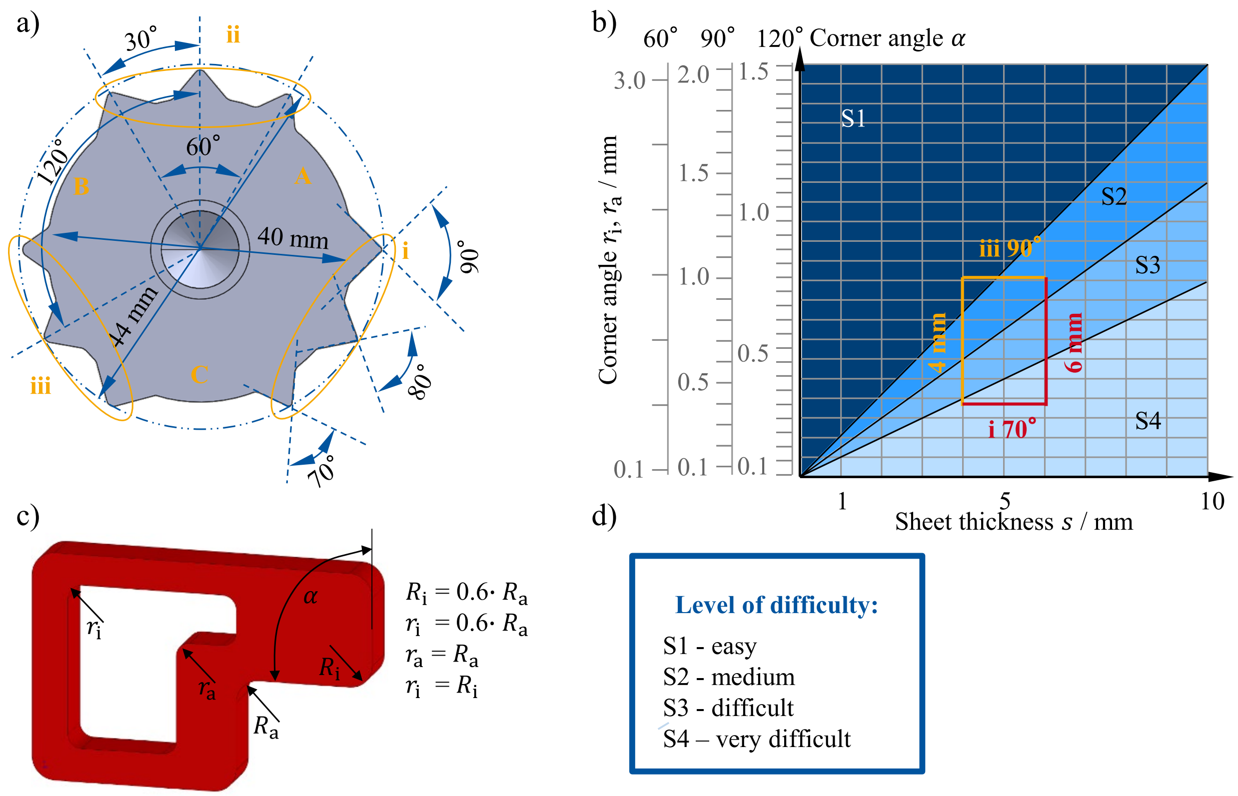

Figure 2: Star part geometry inspired by SSAB [12] a), with location in Feintool evaluation scheme [13] b)-d)

Figure *2*b) depicts the Feintool evaluation scheme [13] and the location of the star part geometry therein. For this evaluation, the reference component in Figure *2*c) is used which shows positive, negative, convex and concave form elements which can be located at hand of multiple Figure *2*b) in order to determine the degree of difficulty according to Figure *2*d). This is done for the arrow part geometry depicted in Figure *2*a) in the following. The star part geometry has various convex geometry elements that pose different challenges to the fine blanking process. The nine convex tooth elements have different tip radii: $r_{i} = 0.5$ mm; $r_{ii} = 0.8$ mm; $r_{iii} = 1.0$ mm. Within each of the three classes i, ii, and iii, there are three teeth, each of which differs in the tooth tip angle. This takes the values $\alpha = 70°$, $\alpha = 80°$ and $\alpha = 90°$. Within the classes, the individual teeth are offset from each other by 30° in each case. Tooth i-70° presents the most difficult fine blanking task, while tooth iii-90° is the easiest to fine blank. Thus, the full-factorial combination of these two features of the nine teeth sparks very different degrees of difficulty for the fine blanking task, which is why the geometry is well suited for basic fine blanking investigations. For the tests described here, plate thicknesses of $s = 4$ mm and $s = 6$ mm were selected, so that in the geometry-dependent difficulty estimation according to the evaluation scheme of the Feintool company [13], all four degrees of difficulty are included in the tests, cf. Figure *2* b)-d). For comparison purposes, specimens of 42CrMo4 hot strip were available at $s = 3.5$ mm and $s = 6.95$ mm. Thus it has to be kept in mind that the sheet thickness is slightly different for both materials. In addition to the general investigation of fine blanking capability, tests were carried out on the fine blanking capability of heated 40MnB4 steel with variation of metal sheet temperature in order to investigate the process. For reasons of comparability with previous test series, these were carried out using a double-drop cutting layout. The so-called arrow section layout can be seen in Figure 3.

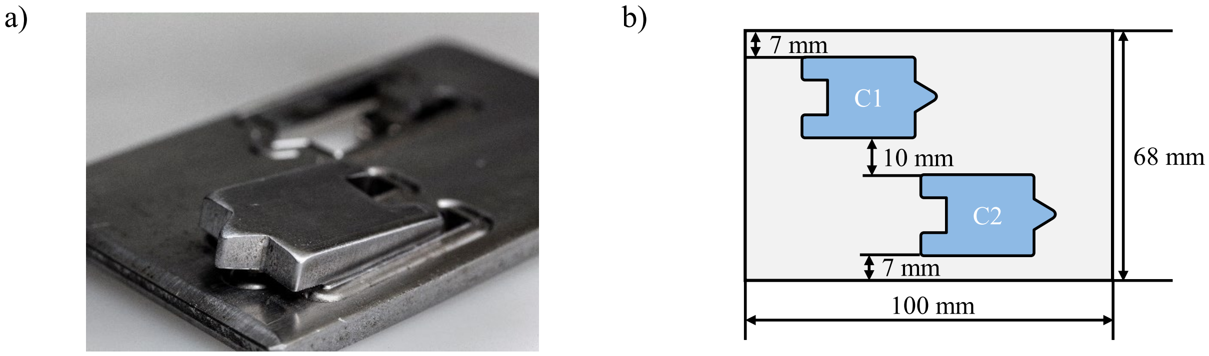

Figure 3: Arrow part geometry, photograph a) and fine blanking layout b)

The heated fine blanking tests were carried out at a sheet thickness of s = 6 mm. The sheet temperature was applied inductively and varied between T = 150 °C and T = 350 °C. In addition, reference tests were also carried out with this geometry at room temperature. The tests were repeated ten times each. This procedure has already been described [14]. All experiments were carried out with subsequent single strokes. In addition to ten repetitions of the fine blanking tests in each case, tests with 50 % and 75 % of the stroke were also carried out for the star part investigations in order to be able to follow the formation of the cut part features.

Results and Discussion

To assess the basic fine blanking suitability of the steel 40MnB4, the cutting results of the star part tests were considered. In particular, the condition of the tooth tips was the subject of the investigation.

The star part geometry corresponds for a sheet thickness of s = 4 mm to a degree of difficulty of S1-S2 in the Feintool classification, i.e. easy to medium. Indeed, with a sheet thickness of s = 4 mm, there were no cracks at the tooth tips, as can be seen in Figure 4.

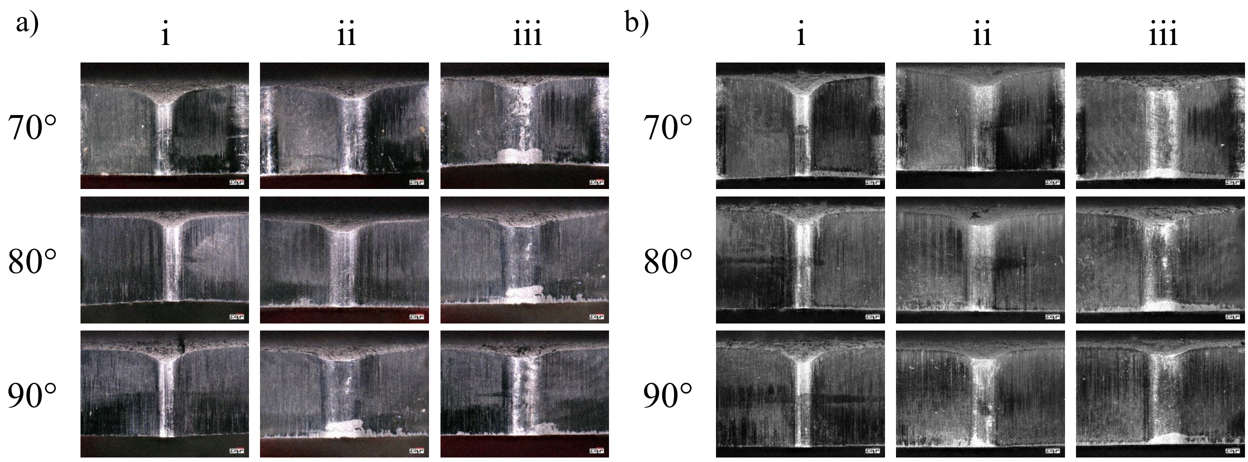

Figure 4: Light microscope images of the tooth tips, s = 4 mm, of 42CrMo4 hot strip a) and 40MnB4 b)

As can be seen in Figure 4, all tooth tips are excellently pronounced except for small breaks. The edge indentation is clearly visible in each case. The cut parts of 40MnB4 meet the second highest tolerance class 100|90 according to VDI 2906 [15]. It is apparent that the part quality even outranks the quality of the 42CrMo4 hot strip specimens.

To further assess the fine blanking capability, the difficulty of the fine blanking task was increased by using a sheet thickness of s = 6 mm. The results are shown in Figure 5.

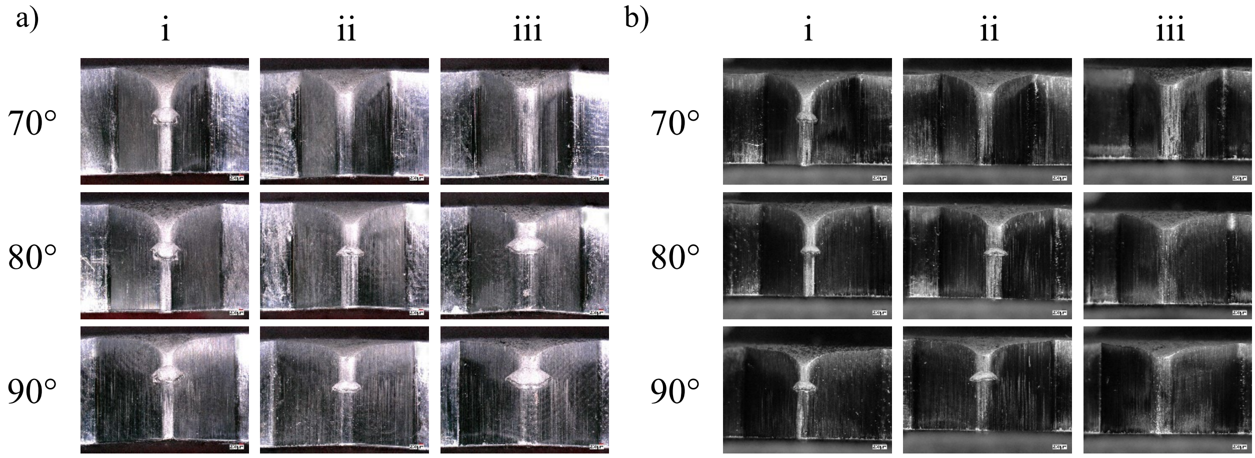

Figure 5: Light microscope images of the tooth tips, s = 6 mm, of 42CrMo4 hot strip a) and 40MnB4 b)

As can be seen in Figure 5, tears appeared at the sheet thickness s = 6 mm. This is valid for both investigated steels. However, since these were not visible at all tooth tips, it can be assumed that the sheet thickness of s = 6 mm allows a good estimate of the fine-blanking properties. Tears were seen on teeth i-70°, i-80° and i-90°, i.e. all teeth with a tooth tip radius of r_i = 0.5 mm. In addition, tears appeared on teeth ii-80° and ii-90°, i.e. on two of three teeth with a tooth tip radius r_i = 0.8 mm. All teeth with the tooth tip radius r_i = 1 mm succeeded without tears for 40MnB4, whereas 42CrMo4 showed tears at iii-80° and iii-90°. For a closer look, light microscope images of the torn tooth tips are shown in Figure 6.

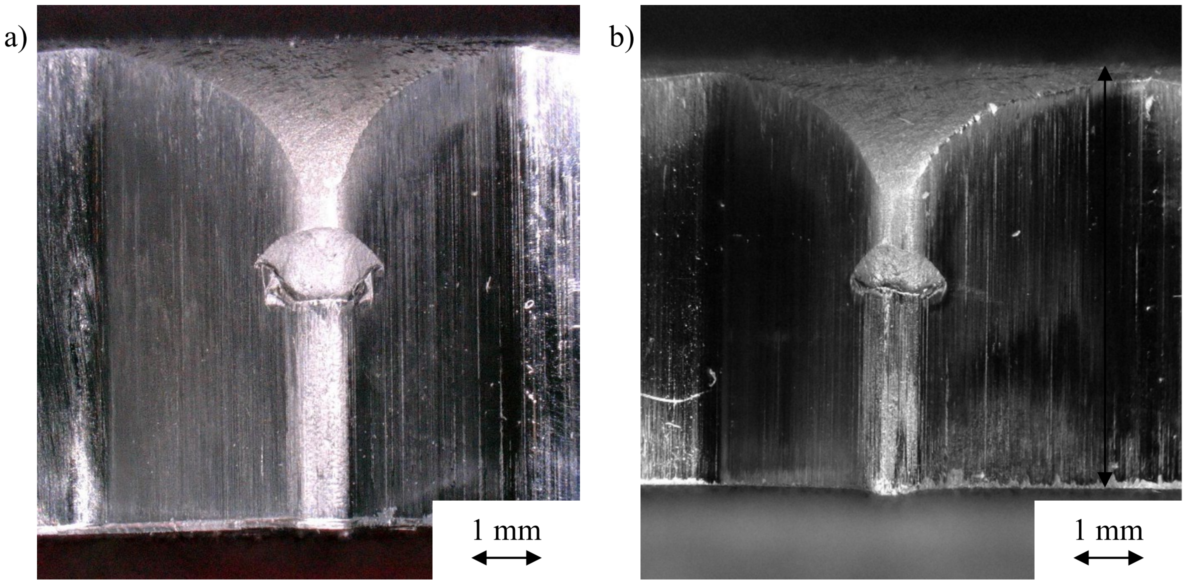

Figure 6: Light microscope images of the tooth tips i-70°, s = 6 mm, of 42CrMo4 hot strip a) and 40MnB4 b)

As can be seen in Figure 6, the tears show a slightly different form for the two materials. The tear at 42CrMo4 seems to be more pronounced. In order to investigate this more in detail, experiments were made with partly fine blanking of 50 % and 75 % of the stroke path. The results can be found in Figure 7.

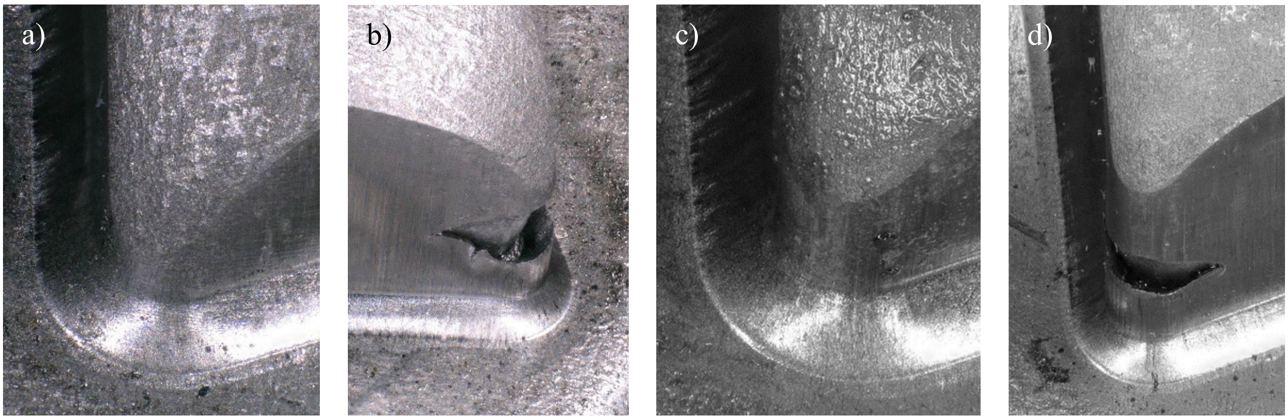

Figure 7: Light microscope images of the tooth tips i-70°, s = 6 mm, of 42CrMo4 hot strip at 50 % stroke path a), at 75 % stroke path b), of 40MnB4 at 50 % stroke path c), and at 75 % stroke path d)

No differences in the tear formation could be found. All tears were not commenced at 50 % stroke path and fully formed at 75 % stroke path. In order to look at this phenomenon in more detail and to identify a trigger of the tear, topography measurements of the cut surface were made and converted to uncurved planes. An exemplary result is shown in Figure 8.

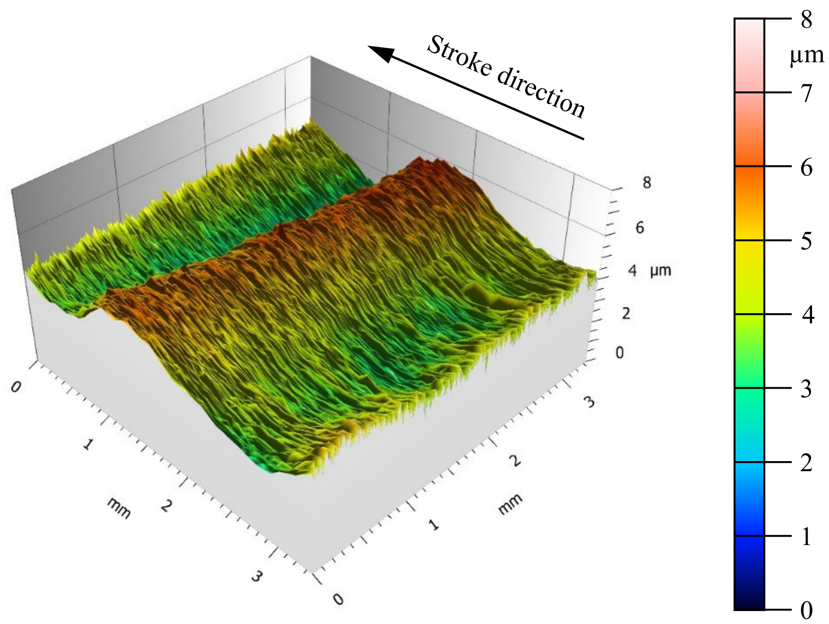

Figure 8: Topography of the intersection in the area A i-ii, plotted by equalization calculation on planar representation.

As can be seen in Fig. 8, the cut surface shows a waviness in the order of 2 µm. It is suspected that this is due to the hardening behavior of the material during forming. This waviness is in all probability the trigger of the tears at the tooth tips.

Another important quality feature for fine blanked parts is the die roll. For this work, the die roll of the fine blanked star part specimens was measured and evaluated at all tooth tips. The measurement was carried out optically with the aid of strip light projection, see Figure 9 a). A subsequent semi-automated comparison of the actual contour determined in this way with the nominal contour with perfectly rectangular edges made it possible to determine the die roll of all star parts, see Figure 9 b).

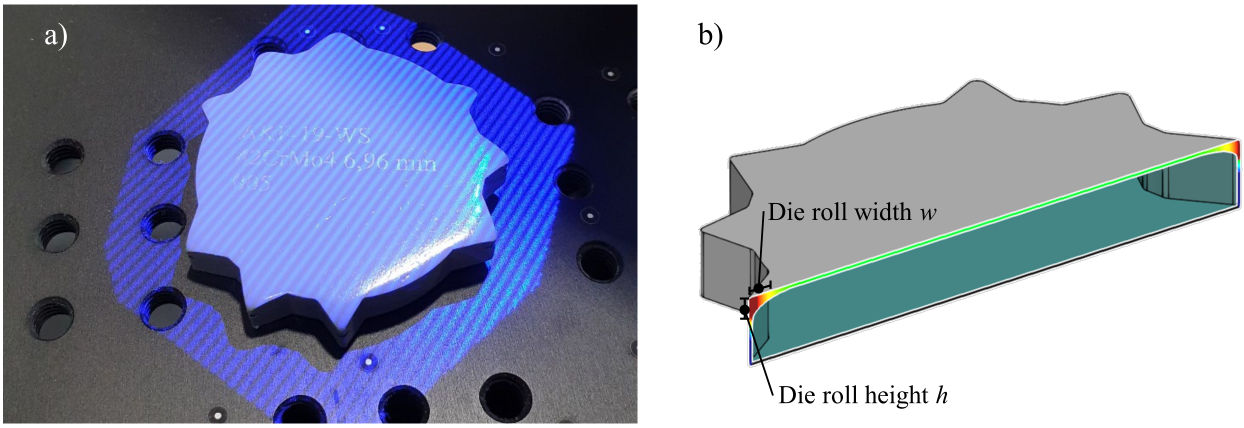

Figure 9: Measuring the die roll: strip light projection a) and comparison of actual-target contour with marking of the die roll b)

The results from the optical measurement of the die roll described in Figure 9 are shown in Figure 10. The die roll height *h* and die roll width *w* of all star part tests with error bars are depicted.

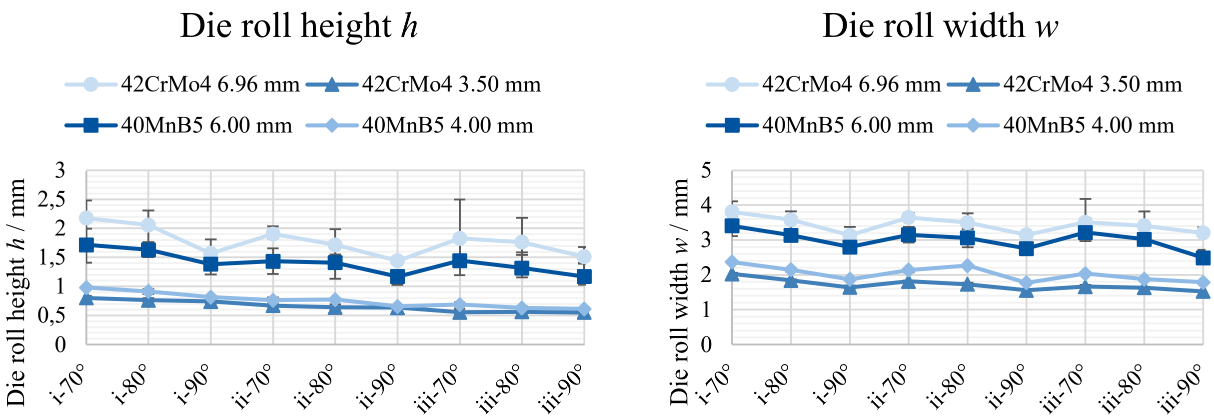

Figure 10: Die roll height and width of the tooth tips

As can be seen in Figure 10, the die roll width and height depend to a large extent on the tooth tip geometry. It seems to be higher for 42CrMo4. The tooth tips show a greater dependence of the edge indentation height and width on the tooth tip angle than on the tooth tip radius. Nevertheless, both variables have a recognizable influence on the formation of the edge indentation. It should be noted that here, too, the largest possible tooth tip angle and the largest possible tooth tip radius simplify the fine blanking task, although the decrease in the tooth tip radius does not appear to be linear. More attention will be paid to this point in future investigations.

In addition to the fine blanking tests with the star part geometry, fine blanking tests were performed with additional inductive heating of the sheet. These are used to evaluate the effects of increased sheet temperature on the process forces. The heating tests were carried out analogously to the quality tests in single stroke, but with a double falling so-called arrow part geometry. This was done to ensure comparability and research continuity to past and future fine blanking tests with elevated sheet temperature. The results of the punch forces can be seen in Figure 11.

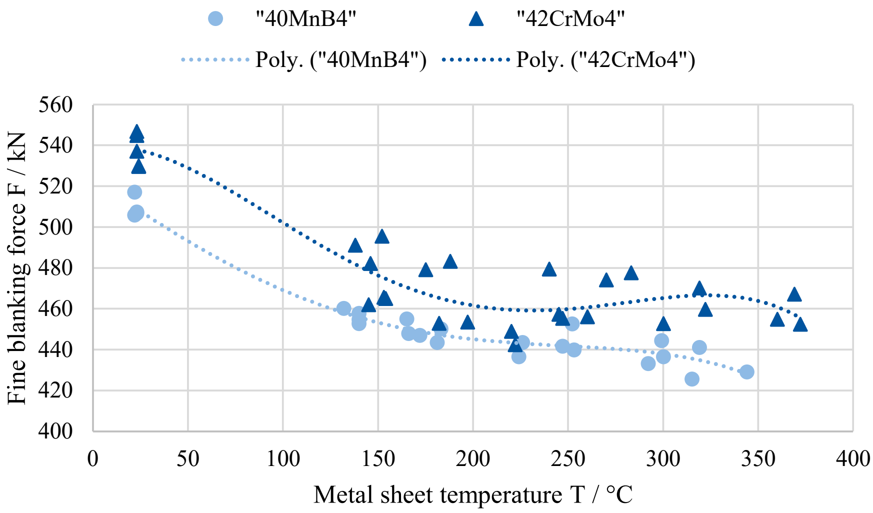

Figure 11: Fine blanking force with variation of the metal sheet temperature for 40MnB4 and 42CrMo4 with polynomial regression curve of 4th degree

As can be seen in Figure 11, sheet temperatures between approx. 150 °C and 350 °C were evaluated. In addition, reference tests were carried out at room temperature. During the tests, the actual sheet temperature was recorded during fine blanking using a thermocouple, so that the punch force values are not plotted above the targeted sheet temperature, but the actual sheet temperature. It can be seen that the fine blanking force decreases with increasing sheet temperature and the decrease is not linear. This is valid for both 40MnB4 and 42CrMo4. Overall, a force reduction of approx. 20 % is observed. The force reduction does not occur linearly. It is assumed that the reason for the non-linearity of the force reduction lies in the dynamic strain aging in analogy to findings on stainless steel [14].

Conclusion and Outlook

The scientific question posed at the outset regarding the fine blanking capability of manganese-boron steel can be answered in summary as follows. The manganese-boron steel 40MnB4 can basically be fine blanked and the specimens show good quality characteristics. Increased sheet temperatures reduce the process forces by significant values. Overall, the tests presented here are therefore very promising.

Acknowledgements

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[15] VDI – The Association of German Engineers: VDI 2906 Blatt 5 - 1994-05 Quality of cut faces of (sheet) metal parts after cutting, blanking, trimming or piercing; fine blanking