Investigation of a partial, inductive short-time heat treatment of thin metal sheets integrated into the forming process

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Abstract. Flanging is a widespread method in the sheet metal working industry to connect same or different materials by forming. Especially the sealing technology makes high demands on the flanging process: a low sheet thickness of the inner eyelet is necessary for proper sealing. The outer edges of the neck rings are mostly manufactured by shear cutting. The quality of the cut surface and the level of the local strain hardening influence decisively the limit of the flanging process by possible cracking. This paper is focused on the dependencies of these factors regarding thin metal sheets of different materials with a thickness down to 100 µm. It could be shown that strain hardening has a stronger effect on the process limits compared to the notch effect of the sheet edges when using standard values for the clearance of the shear cutting tool. Furthermore, a process is investigated with a partial inductive short-time heat treatment of the most deformed edge area. Due to the low thickness of the material and low heat capacities related thereto, it is possible to integrate a recrystallization annealing as single step into the forming process. As a result, the strain hardening can be removed from the affected zone directly between two forming steps to increase the process limits.

Keywords: Sheet metal, Cutting, Heat treatment

1 Introduction

For the manufacturing of permanent, form-locked connections for rotationally symmetric parts made of metal sheets, flanging is often applied because no heat input to the parts or additional joining material is required and high quantities can be produced because of the short joining times [1]. Quality of pre-punched holes which are expanded during the stretch-flanging process, sheet thickness, material and degree of deformation are influencing factors for flanging [1-3]. Regarding the sealing technology in the field of chemical and food industries, corrosion-resistant materials in combination with low sheet thicknesses are required [4]. In this work, the quality of pre-punched holes which can be divided into strain hardening and notch effect, achievable degrees of deformation and an increase of the process limits by inductive short-time heat treatments are investigated [5, 6].

2 Experimental

The material used for the investigation is an austenitic stainless steel 1.4571 with a thickness of 0.1 mm. To ensure a maximum ductility, a bright annealing at 1110 °C and quenching under inert gas was applied after the cold rolling process. The 2D surface specification according to DIN EN 10088-2 allows a cold re-rolling after the heat treatment. Table 1 shows the chemical content and table 2 the mechanical properties and grain size of the coil.

Table 1. Analysis of 1.4571 – 0.10x105.00 mm coil

Analysis					
%	%C	%Mn	%Si	%P	%S
max	0.080	2.000	1.000	0.045	0.015
	0.022	1.160	0.440	0.033	0.003
%	%Cr	%Ni	%Mo	%Ti	-
min	16.500	10.500	2.000	-	
max	18.500	13.500	2.500	0.700	
	16.600	10.560	2.010	0.283	

Table 2. Mechanical properties and grain size of 1.4571 – 0.10x105.00 mm coil

Test results			
	$TYS_{0.2}$ N/mm²	TYS_1 N/mm²	UTS N/mm²
	277	289	622
	Elong. A 80 mm	Hardness HV	Grain size ASTM E112
min	58	-	6.5
max	-	-	8.0
	59.0	125	8.0

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Among others the 0.2% tensile yield stress ($TYS_{0.2}$), 1.0% tensile yield stress ($TYS_{1.0}$), ultimate tensile stress (UTS) are given. By using different methods of cutting, round holes were punched into the metal sheet. The manufactured edges of these pre-punched holes were further investigated. In addition to shear cutting, the manufacturing of thin metal sheets provides other types of cutting. First, a method of punching with a combination of cutting ring and cutting pad and second, a steel rule die cutting process was investigated for comparison.

a.) The shear cutting tool consists of a flat punch, die and blank holder made of 1.2842 with a hardness of 60±2 HRC. The clearance is set to 10 µm which is 10 % of the sheet thickness (Fig. 1 a) [7, 8].

b.) The cutting ring tool consists of a 5 mm thick steel ring, made of 1.2842 with a hardness of 58±2 HRC, which represents the die and a cutting pad, made of 30 mm polyurethane with a Shore hardness of 90 A, which works as inner and outer cutting punch (Fig. 1 b).

c.) The steel rule die tool consists of a pre-hardened and pre-sharpened steel rule, which is fitted into a multiplex wood base. Rubber blocks, positioned on each side of the cutting rule work as ejectors. The cutting base is made of EN AW-5754 (Fig 1 c).

A Hans Schoen UTE/B160 hydraulic press with a maximum press force of 1600 kN was used for the cutting processes.

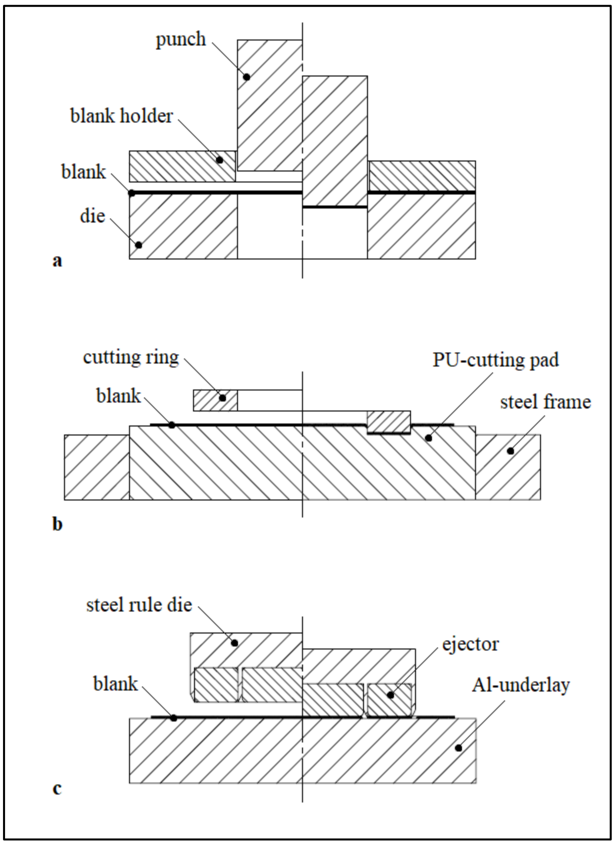

Fig. 1. Schematic drawings of cutting methods; a – shear cutting tool, b – cutting ring tool, c – steel rule die tool

Regarding the notch effect, the cutting edges were investigated with a Keyence VW-9000 digital microscope. The notch depth was measured over a distance of 1 mm at four points each turned 90 °. By measuring six single sections on each point, an averaged notch depth for each measuring distance and sample and a total averaged notch depth for each cutting method could be determined (Fig. 2).

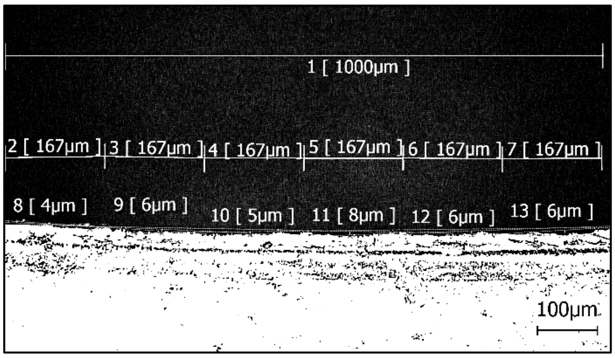

Fig. 2. Microscopic image of notch depth measurements at six sections over 1 mm distance of shear cut sample, top view

The effect of strain hardening was investigated by hardness measurements with a Zwick/Roell BZ2.5/TS1S hardness testing machine in the area of the cutting edge. As testing process, the Vickers HV0.2 was used with a test force of 1.96 N. The indents were made on the cross-sections of the macrosections (Fig. 3).

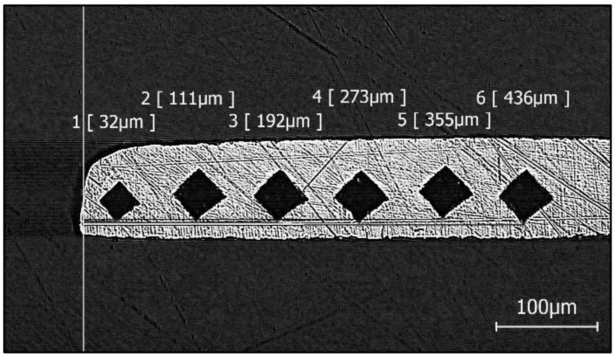

Fig. 3. Microscopic image of cross-section with distances of hardness indents to cutting edge

Due to the sample geometry and the purpose of measuring the strain hardened area, the positioning differs from the standard DIN EN ISO 6507. The first indent was set with a distance of 30 µm to the outer edge of the ring and the following five indents are set with a distance of 80 µm to each other.

Samples of the different cutting processes were then treated with a solution annealing at 1020 °C for 10 min with a Nabertherm N11H annealing furnace and quenched in air at room temperature. The hardness measurements were repeated as mentioned before.

To evaluate the risk of cracking, a hole expanding test following the standard ISO 16630 was used (Fig. 4). A flat drawing punch with a diameter of 60 mm and a radius of 5 mm centered the samples by the pre-punched hole with a diameter of 23.6 mm, which was produced by the shear cutting tool. To minimize the friction during the forming process, an underlay of 0.25 mm PTFE was used. The process was conducted with a mechanical testing machine TIRAtest 28100 at a strain rate of 5 mm/min.

After a reduction in force of 20 N, which indicates cracking, the process was stopped. The expansion ratio of cracking diameter and pre-punched hole diameter provides information on cracking resistance [9, 10]. To investigate the influence of strain hardening and the notch effect, samples with deburred cutting edges, solution annealed samples and solution annealed samples with deburred cutting edges were compared with untreated samples.

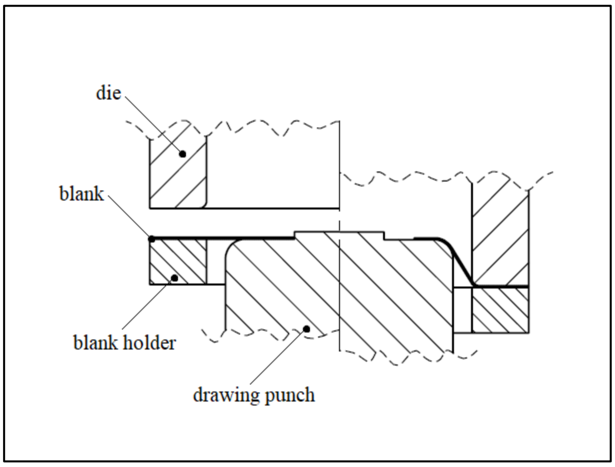

Fig. 4. Schematic drawing of hole expanding test

In the context of the short-time heat treatment, the inductive heating system iew TT2Ht was used with a flat, 50 mm spiral inductor to apply a partial annealing limited to the area of the cutting edge. The temperature was regulated by a SensorTherm Regulus RP10 14 closed-loop control with pyrometer. To compare the results of the inductive short-time heat treatment with the solution annealing, hardness measurements and hole expanding tests were conducted as mentioned.

3 Results and discussion

The measurements of the notch depth give a total averaged notch depth of about 6 µm for the shear cutting tool, 10 µm for the cutting ring tool and 12.5 µm for the steel rule die tool (Fig. 5).

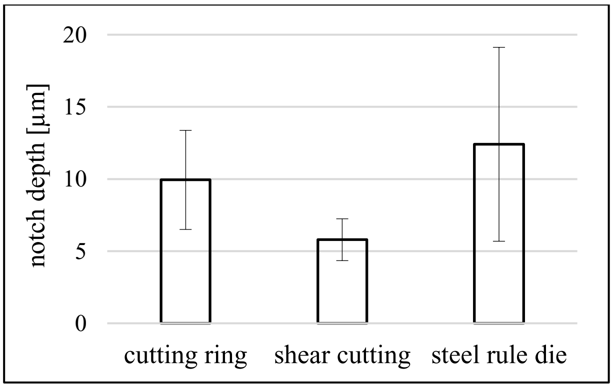

Fig. 5. Total averaged notch depth of cutting methods

Besides the averaged notch depth, the maximum to minimum depth varies considerably from 51 µm to 7 µm regarding the steel rule die tool. Except the notch depth, the form also influences the stress condition. The cutting ring and the steel rule die tool cause deep and sharp notches whereas the shear cutting tool causes flat and rounded notches, which effect significant lower stress peaks (Fig. 6).

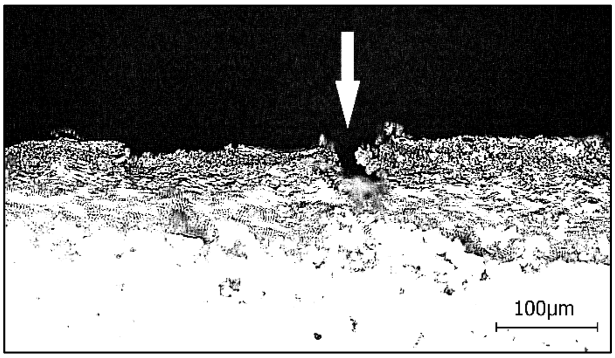

Fig. 6. Microscopic image of deep notch of steel rule die cut sample, top view

Consequently, the shear cutting method with a clearance of 10 % of the sheet thickness causes the lowest notch effect for the investigated material.

The hardness measurement results show a small strain hardened area within a distance of about 50 µm to the cutting edge whereas the area behind remains unaffected (Fig. 7).

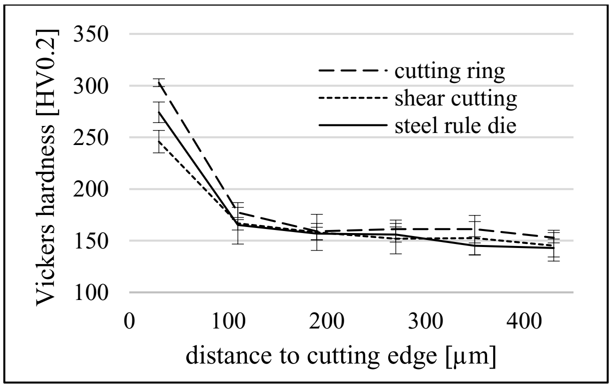

Fig. 7. Hardness profile of investigated cutting methods on distance to cutting edge

The minor scattering at higher distances and the marginal deviation from the specified value of 125 HV0.2 of hardness result from the positioning of the indents on the cross-section with a maximum possible distance of 50 µm to each surface. Regarding the punching methods, the cutting ring tool causes the highest strain hardening which can be traced to the highest hardness of about 300 HV0.2. The steel rule die cut edges show a hardness of about 275 HV0.2 and with a hardness of about 245 HV0.2 the shear cutting tool causes the lowest strain hardening for the considered methods.

To reduce the strain hardening which is caused by the cutting process, it is necessary to achieve a recovery, even better a recrystallization. Recrystallization requires a critical degree of deformation in the area of the cutting edge. The measurement results of the hardness after solution annealing show a complete degradation of the strain hardening (Fig. 8).

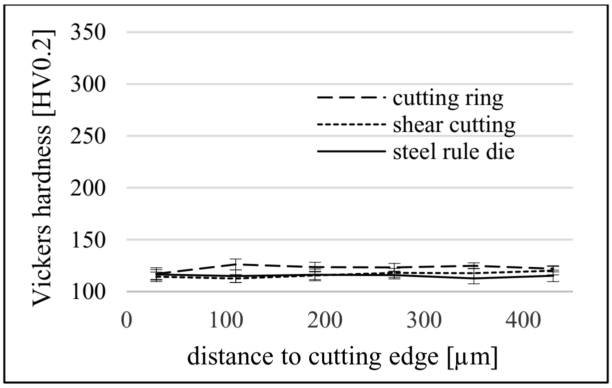

Fig. 8. Hardness profile of investigated cutting methods on distance to cutting edge after solution annealing

With an averaged hardness of about 120 HV0.2 no significant differences between the cutting methods or measuring points exist. The lower hardness values compared to the values of the untreated samples could result from a cold re-rolling, which is allowed due to the specified surface finish. The solution annealed condition is the reference for the inductive short-time heat treatment. Due to the previous findings, the shear cutting method was applied for further investigations.

The hole expanding test results for the solution annealed and deburred condition show the process limits with a maximum expansion ratio of 1.52 (Fig. 9)

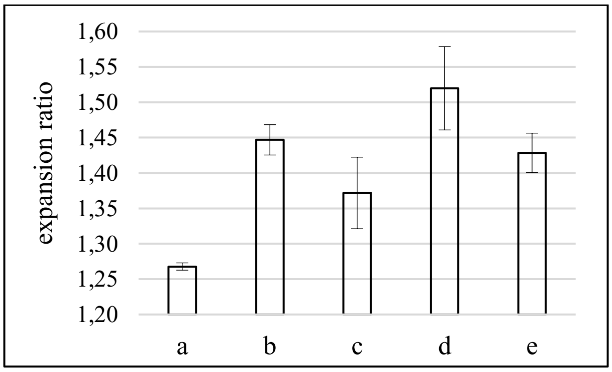

Fig. 9. Expansion ratio of different conditions – a.) untreated b.) solution annealed c.) deburred d.) solution annealed, deburred e.) inductive annealed

The expansion ratio of the deburred condition with 1.37 is lower than the solution annealed condition with 1.45. To ensure that the strain hardening is unaffected by the deburring, hardness measurements are conducted which show values inside the standard deviation of the untreated shear cut samples (Fig. 10). Consequently, the strain hardening has a higher influence on the risk of cracking than the notch effect. The untreated samples as reference measurements show the lowest expansion ratio with a value of 1.27.

To remove the strain hardening by an inductive short-time heat treatment, an optimized heating process for the investigated material is determined. The samples were placed with a distance of 5 mm under the inductor. With a high frequency generator power of 1.94 kW, the cutting edge reached a temperature of 1020 °C in 1.8 s (Fig. 11).

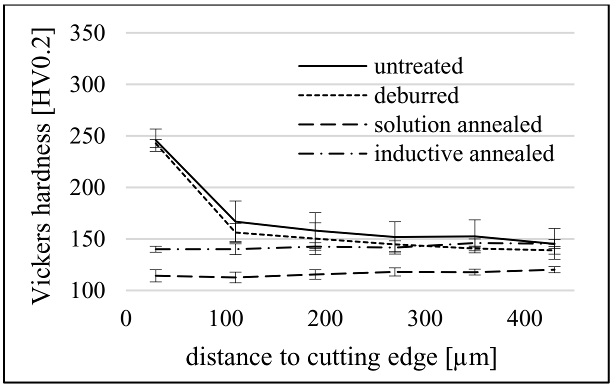

Fig. 10. Hardness profile of different conditions on distance to cutting edge

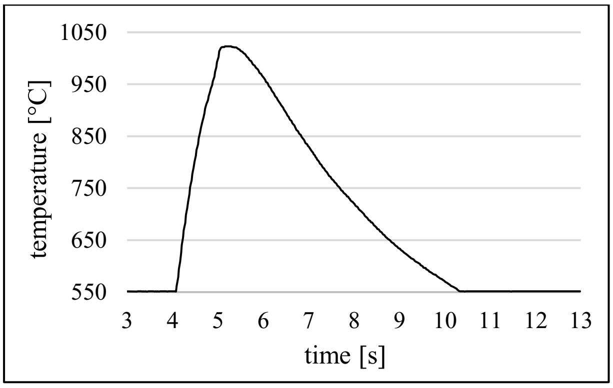

Fig. 11. Temperature profile of an inductive annealed sample with a hold time of 0.5 s

After testing different heating parameters, a hold time of 0.5 s was considered to be suitable to remove the strain hardening as shown by the reduced hardness values (see Fig. 10). The differences of the hardness values between the solution annealed and inductive short-time annealed samples must be caused by the duration of the heat treatment. The expansion ratio of 1.43 for the inductive annealed condition almost achieves the value of the solution annealed condition which is 1.45 (see Fig. 9). The marginal higher expansion ratio of the solution annealed samples is caused by the higher reduction of strain hardening.

4 Conclusion

In this work, different processes which are usually applied for flanging were investigated: First, the manufacturing of the pre-punched hole which is an important part for the further forming process and second, the risk of cracking during hole expansion and opportunities to increase the process limits. It could be shown, that for thin 1.4571 stainless steel sheets with a thickness of 100 µm it is possible to apply unconventional cutting methods like cutting ring or steel rule die tools. The quality of the different cutting methods is based on the factors strain hardening and quality of the cutting surface which causes the notch effect. The shear cutting tool provides with about 6 µm the lowest averaged notch depth including a significant lower statistic variance. The hardness in the area of the cutting edge increased from about 155 HV0.2

of the basic material to about 245 HV0.2 which is a lower strain hardening than the next-best alternative cutting method with 275 HV0.2. To separate the influence of notch effect and strain hardening, the hole expanding test was conducted which showed that the solution annealed samples have a higher expansion ratio of 1.45 compared to the deburred samples with a ratio of 1.37. In order to integrate an annealing into the forming process, the inductive short-time heat treatment was adapted to reduce the strain hardened area with an annealing for 0.5 s at 1020 °C. The inductive annealed samples reached an expansion ratio of 1.43 which is marginal lower than the ratio of the solution annealed condition. As a result, the shear cutting method should be used for flanging or comparable forming processes when higher expansion ratios of pre-punched holes are required. The strain hardening due to the cutting process has a greater influence regarding the limits of hole expansion than the notch effect. The integration of the inductive annealing into forming processes without impermissible heat input to the forming tools seems possible due to the low heat capacity of the thin raw material which has to be considered in further investigations.

References

1. E. Doege, B.A. Behrens, *Handbuch Umformtechnik*, 386–388 (2006)
2. K. Lange, *Umformtechnik*, 522–526 (1990)
3. C.H. Phan, S. Thuillier, P.Y. Manach, Metall and Mat Trans A **46**, 3502-15 (2015)
4. P. Gümpel, *Rostfreie Stähle*, 3 (2016)
5. W. Weißbach, *Werkstoffkunde*, 48–49 (2015)
6. H.J. Bargel, G. Schulze, *Werkstoffkunde*, 106–108 (2000)
7. S.M. Yi, B.Y. Joo, M.S. Park et al., Microsyst Technol **12**, 877-82 (2006)
8. J. Xu, B. Guo, D. Shan, Int J Adv Manuf Technol **56**, 515-22 (2011)
9. J.I. Yoon, J. Jung, H.H. Lee et al., Met. Mater. Int. **22**, 1009-14 (2016)
10. X. Chen, H. Jiang, Z. Cui, C. Lian, C. Lu, Procedia Engineering **81**, 718-23 (2014)