Micro-scratch tests as a method for determining the wear resistance of high-speed blanked surfaces

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Abstract

Compared to conventional cutting processes such as normal or fine blanking, high-speed blanking (HSB) is an economically and ecologically relevant alternative to produce sheet metal parts. Depending on the material and the process parameters, the microstructure is significantly affected, and adiabatic shear bands (ASB) can form due to the localisation of the induced deformation. The resulting HSB surfaces are characterised by high hardness, small rollover depth and width, low roughness, and almost no burr. Therefore, HSB is a promising strategy for producing blanked surfaces, which can be used directly as functional surfaces without further post-processing steps. Besides the surface quality, properties like the wear resistance are relevant for technical applications. To enable the production of functional surfaces, which meet the requirements for the application, the understanding of the relationships between the blanking process parameters, the resulting microstructure, and the surface properties is essential. As standardised macroscopic wear testing methods are often not applicable to the geometrically complex shear-cut surfaces, in this study a first approach was taken utilising the micro-scratch test method for determining the scratch resistance directly measured on the blanked surface.

Keywords

Blanking, Surface Analysis, Wear

1 Introduction

High-speed blanking (HSB) is an economically and ecologically relevant alternative to produce sheet metal parts when compared to conventional cutting processes such as normal or fine blanking or laser cutting. Depending on the material and the process parameters, the microstructure is significantly affected, and adiabatic shear bands (ASB) can form due to the localisation of the induced deformation. The resulting HSB surfaces are characterized by high hardness, small rollover depth and width, low roughness, and almost no burr as found by Neugebauer et al. (2010), Schmitz et al. (2020) and Winter et al. (2021). Therefore, HSB is a promising strategy for producing blanked surfaces, which can be used directly as functional surfaces without further post-processing steps. Besides the surface quality, properties like the wear resistance are relevant for technical applications. To enable the production of functional surfaces, which meet the requirements for the application, the understanding of the relationships between the blanking process parameters, the resulting microstructure, and the surface properties is essential.

In this study, the determination and evaluation of the wear properties of HSB surfaces are in focus. A particular challenge here is that, due to the use of circular punches, the blanked surface is not a flat surface (**Figure 1**). As standardised macroscopic wear testing methods are often not applicable to the geometrically complex shear-cut surfaces, there is a need for new and adjusted experimental set-ups. A further challenge lies in realising a microstructure-sensitive testing method in order to identify correlations between the process, the microstructure, and the wear properties. Rojacz et al. (2023) showed in their study the possibility of microstructure-sensitive testing using nano-scratches to identify the wear mechanisms influenced by the microstructure. These micro- and nanoscale investigations must be carried out on metallographically prepared material sections (Gane and Skinner, 1973; Xiao et al., 2013). However, the aim of this study is to determine the property profile of the HSB surface in as-blanked state. Polishing and grinding processes as part of a metallographic preparation would remove this surface area and therefore no longer allow any reliable statement to be made about the functionality of the surface. Consequently, the scratch tests were carried out directly on the non-planar, rough HSB surface, which proved to be challenging. The extent to which this method is suitable for determining the resistance against abrasion as a function of the process parameters is examined in more detail below.

2 Experimental methods

2.1 Material and blanking process

For this study, surfaces resulting from different blanking process parameters were investigated. The non-age hardenable aluminium alloy 5754 and the press-hardened steel 22MnB5 were used as commercially available sheet material with a thickness of 2 mm. From both sheet materials, coins with a diameter of 20 mm were blanked with different process parameters listed in **Table 1** using high-speed blanking presses (MPM formerly ADIAPRESS, France). The specific machine set-up is described by Winter et al. (2021) for the ADIAflex® and by Schmitz et al. (2024) for the ADIAClip1000J®.

Material	**Machine and die**	**Blanking parameters**	**Surface roughness R_a**
Al5754	ADIAflex, 20.2 mm die	0.02 m/s blanking speed, 5 % clearance	2.66 ± 0.04 µm in clean cut area, 9.20 ± 0.39 µm in fracture area
Al5754	ADIAflex, 20.2 mm die	10 m/s blanking speed, 5 % clearance, 1000 J blanking energy	1.23 ± 0.02 µm in clean cut area, 5.52 ± 0.15 µm in fracture area
22MnB5	ADIAclip, 20.1 mm die	8 m/s blanking speed, 2.5 % clearance, 600 J blanking energy	4.04 ± 0.24 µm in clean cut area, 3.30 ± 0.25 µm in fracture area
22MnB5	ADIAflex, 20.2 mm die	10 m/s blanking speed, 5 % clearance, 1000 J blanking energy	3.67 ± 0.06 µm in clean cut area, 2.66 ± 0.13 µm in fracture area

Table 1: *Investigated blanked conditions resulting from different process parameters.*

2.2 Micro-scratch tests

For the micro-scratch tests, a universal nanoindenter UNAT (ASMEC, Germany) with a spherical diamond indenter with a 10 µm tip radius was used. The test data were analysed by the software InspectorX V3. In **Figure 1** the non-planar surface of the blanked coin and the application of the micro-scratch, perpendicular to the blanking direction, are shown schematically.

The three-step standard procedure for scratch testing consists of a pre-scan, the scratch and a post-scan. By the pre-scan, the initial surface profile is determined using a small load of 1 mN for the aluminium alloy and 2 mN for the manganese-boron steel, respectively. This profile serves as a reference for the unscratched surface with initial roughness and is later subtracted from the profile determined by the post-scan. Further, due to the radius of the blanked coins, a correction function was applied by the software to eliminate the influence of the surface curvature on the measured profile by pre- and post-scan.

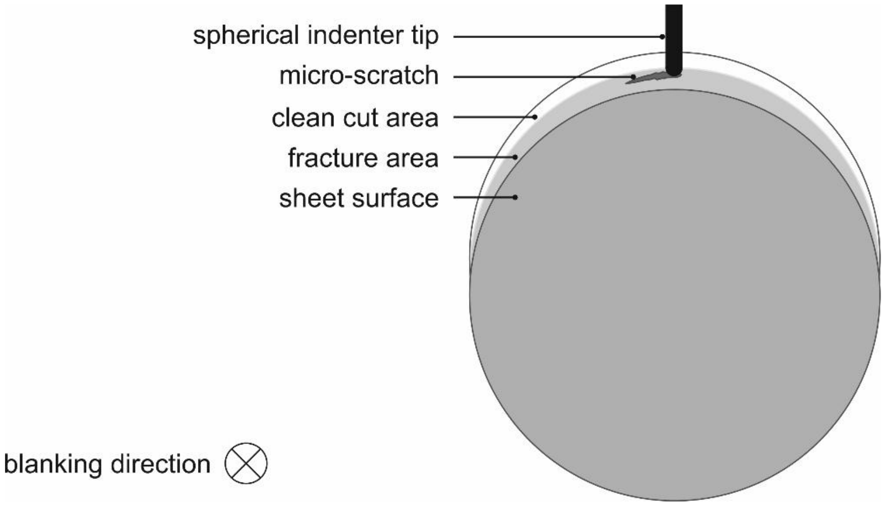

***Figure 1**: Schematic representation of the micro-scratch being positioned on the blanked surface perpendicular to the blanking direction.*

For these first experiments, the micro-scratch test parameters listed in **Table 2** were used. These parameters ensured that no major cracking or flaking of the material occurred during the scratch, ensuring a correct testing procedure. The progressive force mode was used for determining critical loads causing material failure depending on the blanked surface and the process parameters.

Material	**Scratch length**	**Applied normal force**	**Scratch speed**
Al5754	200 µm	50 mN, linearly progressive	5 µm/s
22MnB5	200 µm	300 mN, linearly progressive	10 µm/s

***Table 2:** Parameters used for the micro-scratch testing on the blanked surfaces.*

3 Results and discussion

For the aluminium alloy, the different blanking process parameters had a significant influence on the resulting surface (see **Figure 2 a, c**). The high-speed blanked surface exhibits a smaller height of the clean-cut area but a larger fracture area, and the roll-over height is significantly reduced. Further, the width of the shear zone resulting from the induced deformation by the blanking process is smaller for a higher blanking speed due to a more pronounced localisation of deformation (see **Figure 2 b, d**). The surface roughness after high-speed blanking is approximately halved when compared to the blanking speed (see **Table 1**).

For 22MnB5, there is no significant difference between both blanked conditions (see **Figure 3 a, d**). The resulting appearance and the roughness of the surfaces (see **Table 1**) are comparable, despite the different blanking speeds and clearances used. The metallographically prepared cross sections of the blanked steel show for both parameter sets pronounced adiabatic transformation shear bands with a width of approximately 17–22 µm (see **Figure 3 c, f**).

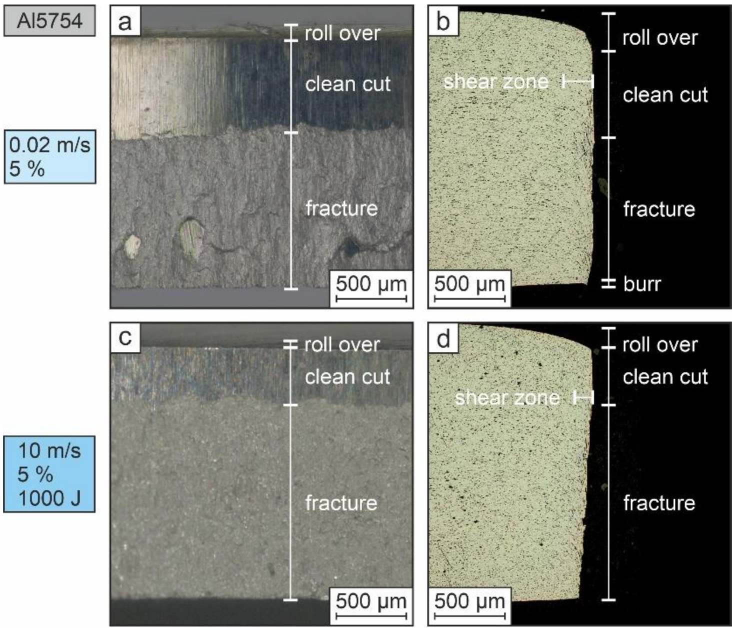

***Figure 2**: Optical micrographs of (a, b) conventionally and (c, d) high-speed blanked surface of the aluminium alloy 5754.*

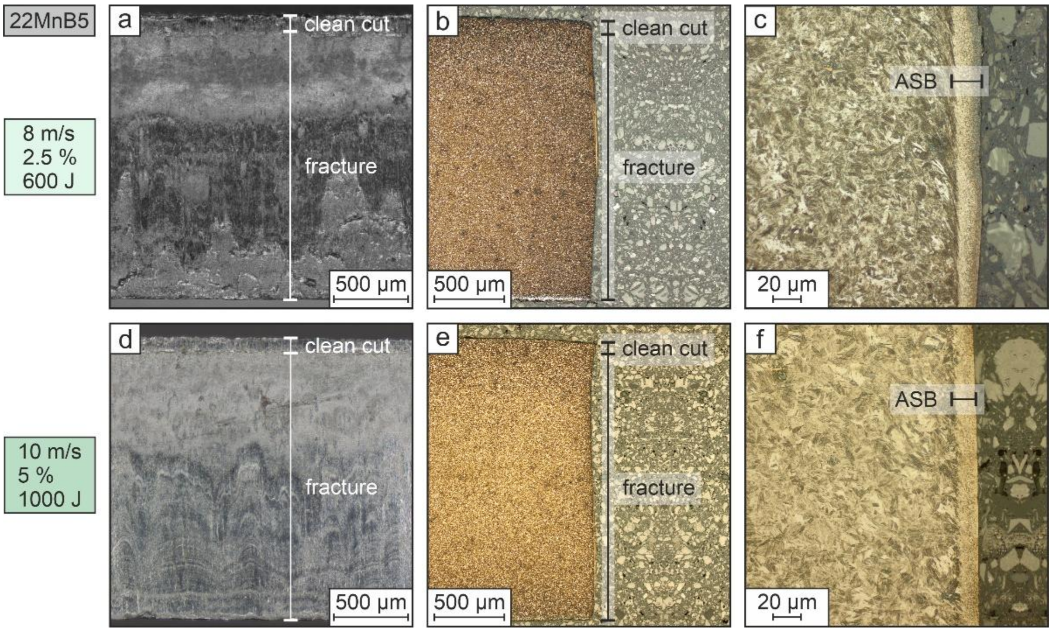

***Figure 3**: Optical micrographs of high-speed blanked surfaces of the used 22MnB5: (a–c) lower blanking speed and clearance, (d–f) higher blanking speed and clearance.*

The surfaces of both blanked conditions for each material, respectively, were tested using micro-scratches. **Figure 4** shows exemplarily scanning electron micrographs of the scratched high-speed blanked surfaces. Secondary electron contrast was used for visualisation of the surface profile of the micro-scratches. It is noticeable that the scratch could be applied in full length without interruptions caused by surface heterogeneities. Further, no material flaking or cracking is visible in the scratched area for the used magnification.

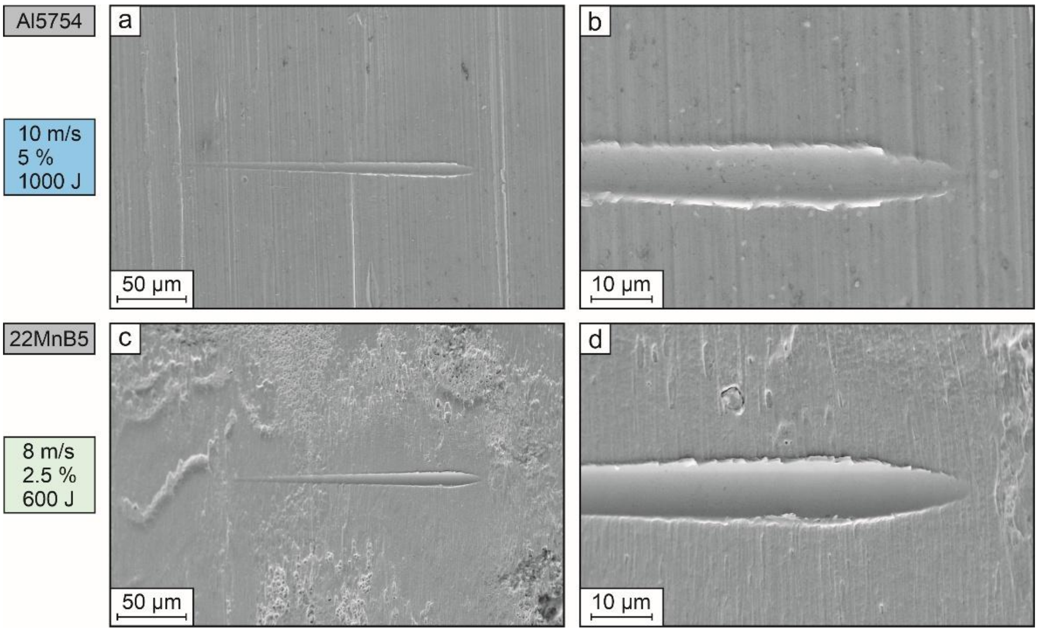

***Figure 4**: Secondary electron images of the scratched (a, b) aluminium alloy 5754 in the clean cut area and (c, d) steel 22MnB5 in the shear band area. a, c) full-length of micro-scratch and b, d) end of micro-scratch.*

Table 3 lists selected values determined from the micro-scratch tests under progressive loading. The most important values are the critical load under which the first cracks occur (L_{c1}) and the distance that the indenter has travelled to this point (x_1). The software calculates these values from the determined post- and pre-scan detecting jumps in the profile.

These results indicate a tendency that for the aluminium alloy, the first cracks form at a higher normal force and at a higher distance for a higher blanking speed. As this corresponds directly to the wear behaviour, these first experiments indicate a higher resistance against scratches both in the clean cut and in the fracture area and, therefore, an improved abrasive wear behaviour of the high-speed blanked aluminium surface. Further, the friction coefficient, calculated by tangential force divided by normal force, is lower for the high-speed blanked condition, indicating a smaller wear rate when compared to the conventionally blanked one.

For both high-speed blanked steel surfaces processed by different blanking speeds, the micro-scratch results show no significant differences regarding the load at first crack formation L_{c1} or the distance x_1. However, in this case, not only the blanking speed, but also the clearance and the energy input were varied, which makes it difficult to compare the values. Therefore, further investigations are needed for 22MnB5. The micro-scratches could only be applied to the fracture area of the blanked surface, which corresponds to the shear band area. Due to the small width of the clean-cut area of all high-speed blanked 22MnB5 samples, micro-scratch testing was not possible in this area, as the indenter could not be positioned without causing material cracking and break-out at the specimen edge, which prevents a correct testing procedure.

Material	**Blanking parameters**	**Measurement area**	**Micro-scratch results at first crack formation**		
			distance x_1	**load L_{c1}**	**friction coefficient μ_f**
Al5754	0.02 m/s, 5 %	clean cut	23.39 µm	4.44 mN	0.083
		fracture area	15.32 µm	3.07 mN	0.095
Al5754	10 m/s, 5 %, 1000 J	clean cut	26.95 µm	9.30 mN	0.046
		fracture area	125.05 µm	30.64 mN	0.003
22MnB5	5 m/s, 2.5 %, 600 J	fracture area	14.42 µm	17.43 mN	0.005
22MnB5	10 m/s, 5 %, 1000 J	fracture area	15.95 µm	18.84 mN	0.020

Table 3: *Results of the micro-scratch tests for conventionally cut (0.02 m/s) and high-speed blanked (5 and 10 m/s) Al5754 and 22MnB5 samples.*

4 Conclusion and outlook

The first results presented in this study demonstrate the suitability of micro-scratch tests for determining the resistance against abrasion for non-planar blanked surfaces. However, as the aim of this method is the evaluation of the wear resistance of blanked surfaces depending on the process parameters and the resulting surface and microstructural properties, further work is necessary regarding suitable parameters for micro-scratch testing.

In the next steps, the influence of the tip radius of the spherical indenter will be considered. The used indenter tip radius of 10 µm is most suitable for a low surface roughness, which is near to a grinded condition. As the low surface roughness after high-speed blanking is still higher than after grinding, larger tip diameters will be used to minimise the influence of the surface topography. This will allow for a higher applied normal force as well, enabling a broader testing parameter range. Further, to get an understanding of the wear mechanisms influenced by the surface properties after blanking, other key values like the scratch energy density have to be determined. For analysing the scratch energy density, constant normal force has to be applied, and the volume of the scratch has to be measured using, for example, laser scanning microscopy. Besides these approaches, more tests have to be conducted to allow for a statistical evaluation, which is necessary for enabling the separation of influencing factors like surface roughness and surface microstructure. Regarding the separation of effects, micro-scratches will also be applied on metallographically polished cross sections of the blanked surfaces.

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