Hole quality and burr reduction in drilling aluminium sheets

Pilny, Lukas; De Chiffre, Leonardo; Piska, Miroslav; Villumsen, Morten F.

Published in:
International Conference NEWTECH 2011

Publication date:
2011

NEWTECH 2011

NEW TECHNOLOGIES IN MANUFACTURING
ISBN 978-80-214-4267-2

HOLE QUALITY AND BURR REDUCTION IN DRILLING ALUMINIUM SHEETS

Lukáš Pilný[1,2], Leonardo De Chiffre[1], Miroslav Píška[2], Morten F. Villumsen[3]

[1]Technical University of Denmark, Department of Mechanical Engineering, Kgs. Lyngby, Denmark
[2]Brno University of Technology, Faculty of Mechanical Engineering, Brno, Czech Republic
[3]Bang & Olufsen, Struer, Denmark
ldch@mek.dtu.dk

ABSTRACT

Optimization of the metal drilling process requires creation of minimum amount of burrs and uniform appearance of the drilled holes. In this paper, an experimental investigation was performed on 2 mm sheets of wrought aluminium alloy Al99.7Mg0.5Cu-H24, using 1.6 and 2 mm diameter drills. Cutting data, clamping conditions, and drill geometry were varied in order to optimize the process and reach the desired quality. The results revealed possible reduction of burr occurrence on both the entry and exit side of the sheet, requiring no additional deburring. The demand on the uniform appearance of drilled holes was fulfilled as well as high productivity achieved. Such optimized process results in a noticeable production cost reduction.

KEYWORDS: drilling, aluminium, burr minimizing, measurement, vacuum clamping

1. INTRODUCTION

During the drilling in a metal sheet, burrs form on both the entry and exit side of the hole as a result of plastic deformation of the workpiece material. Burrs occurrence can cause many problems such as functional problems, small injuries of assembly workers, assembly issues, etc., requiring an additional deburring process for removal. These unwanted burrs are typically harder than the workpiece material because of a strain-hardening effect. The costs associated with removing these burrs as a percentage of manufacturing cost varies up to 30 % for high precision components such as aircraft engines, etc. In automotive components, the total amount of deburring cost for a part of medium complexity is in the range of 15 to 20 % of the manufacturing expenses [1]. There are many papers dealing with different kinds of deburring processes, but these are costly, very time consuming, and non-value-adding operations [2].

Therefore, it is very important and the best strategy to minimize or prevent burrs from occurrence by controlling the process at all stages of the process chain. This control requires good knowledge from the design of the component through production planning with respect to burr creation on the workpiece. There is much recent work focused on the burr formation process and how to control or minimize this unwanted phenomena by variation of process variables. The successful control at all production stages can result in producing burr-free components or significant deburring cost reduction.

A uniform appearance of the drilled holes is also among the requirements of a well optimized production process. This demand is of utmost importance when a single workpiece contains a great number of drilled holes (e.g. sound speaker grills). In such case, any defect in the hole quality, resulting in different appearance, represents a non-permissible design.

This work was focused on optimization of the production of sound speaker grilles by drilling. The study was a collaboration among DTU – Technical University of Denmark, BUT – Brno University of Technology (the Czech Republic) and the company Bang & Olufsen A/S (Denmark). The ultimate goal of this research is to achieve reduction of hole entry and exit burrs, uniform appearance of the drilled holes, while reaching the highest possible productivity of the drilling process.

2. BURR MEASUREMENTS

The ISO 13715 standard [3] defines burr size only by one value, as a deviation from the ideal geometrical edge. However, previous research has shown that burrs are so variable that for proper investigation it is required to enlarge the number of measured burr dimensions. It has been revealed that the burr thickness contributes more to deburring costs than the burr height [4]. The random cross-section has been used for describing basic burr parameters [5]. But measurement of these detailed burr characteristics are very time consuming and not all measuring methods are capable to evaluate these characteristics. Hence, the most often and easily measured characteristics are burr height and thickness (width) [6].

Burr height, width, and root width were measured in the present investigation (see fig. 1). The measured burr root width, according to [5], represents the distance from drilled hole circumference to the curvature where plastically deformed base material in the burr begins. In case of small proportion of an excessive burr height present, caused by separation of a drilling cap, its height (EBhe) and angular proportion (θ) were measured in addition to the representative burr height.

There are many different methods of burr detection and measurements. The choice of an appropriate system depends on application conditions, requested measurement accuracy and burr characteristics to be measured. Contact stylus methods are slow, and plastic deformation due to the

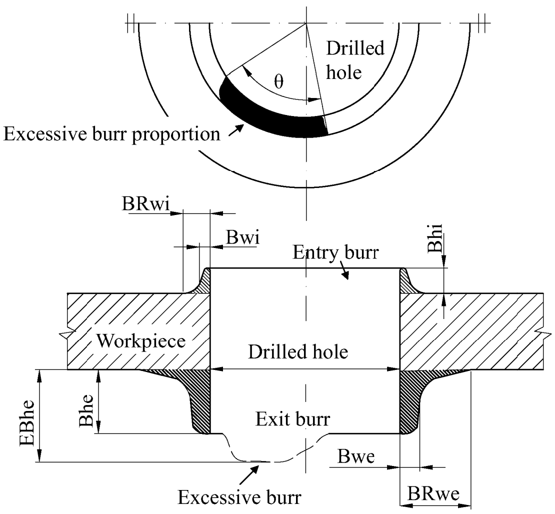


Fig.1. Description of measured burr geometry, where: Bhe – exit burr height, Bhi – entry burr height, BRwe – exit burr root width, BRwi – entry burr root width, Bwe – exit burr width, Bwi – entry burr width, EBhe – Excessive burr height, θ – angular proportion of excessive burr.

Fig.2. 3D reconstruction of burr scanned by infinite focus 3D microscope.

tip pressure might reduce the real burr height. Moreover, the real burr profile is falsified because of the conical shape of the tip. Various optical systems can be advantageous in burr measurements [6, 7].

2.1. Burr height measurement

Burr heights were measured by using an infinite focus 3D microscope from Alicona Imaging [8]. This optical system provides a non-contact measurement which means that no surface damage is possible and the measurement results are much less error prone. Since the burr edges have steep angles creating difficulties with light reflection, the measured workpiece was placed on a stair-step fixture, providing an inclination angle of 22° for a better scanning procedure. A magnification of 5X was used and a 3D reconstruction (see fig. 2) of whole burr formed was made by scanning of 2D horizontal layers with vertical resolution of 5 μm in between 2 focused levels (lower = drilled sheet surface and upper = bit above the top of the burr height in Z-direction). In order to avoid unintentional peaks in the 3D reconstruction, a polarization filter was utilized. This strategy provided fast measurement (approx. 20 s for the whole burr scanning and 3D reconstruction) with later evaluation on stationary PC and an entire burr perimeter involved in measurements. This PC was equipped with MeX 5.1 software from Alicona Imaging [9], using profile analysis tool.

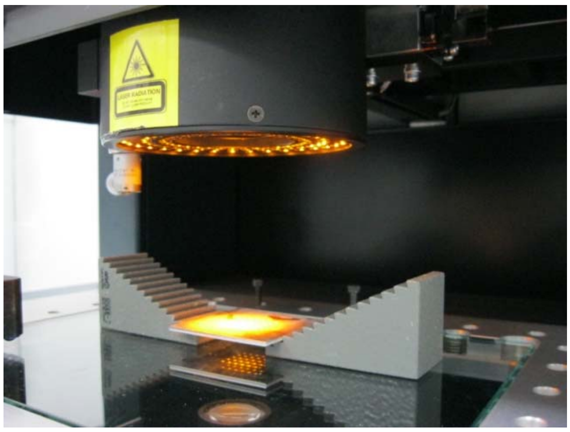


Fig.3. Workpiece fixture when burr widths measured by an optical CMM.

2.1. Burr width measurement

Burr widths and burr root widths were measured by a DeMeet 220, an optical coordinate-measuring machine from Shut Geometrical Metrology, equipped with 5X magnification lens. The workpiece was placed in a horizontal position via the stair-step fixture (fig.3), light setting was accordingly adjusted, and picture of the workpiece was taken by the CCD-camera. The optical CMM measuring principle is based on measuring on the picture. The picture of the workpiece is digitized into an array containing information of the light intensity of each pixel. A circle was fitted near a burr edge to measure, measuring range and dark to light side orientation was adjusted. Subsequently, the picture processing computer automatically detects the edge from transition in the picture between dark and light (see fig. 4). Such measurement strategy involved the entire burr perimeter in a measurement, providing a traceable result with an automatically averaged value of the width around the hole periphery.

3. PLANNING OF EXPERIMENTAL INVESTIGATIONS

The experimental work was done in three subsequent tests as follows:

- **Preliminary test** (evaluation of the influence of drilling process parameters, generally recognized as heavily influencing the burr occurrence according to previous research)
- **Clamping system investigation** (a clamping system in the interest of minimizing exit burr formation was constructed and its influence on burr formation was evaluated)
- **Drill geometry investigation** (contains the influence of different tool geometry on burr formation and uniformity of drilled holes while the special clamping system was utilized)

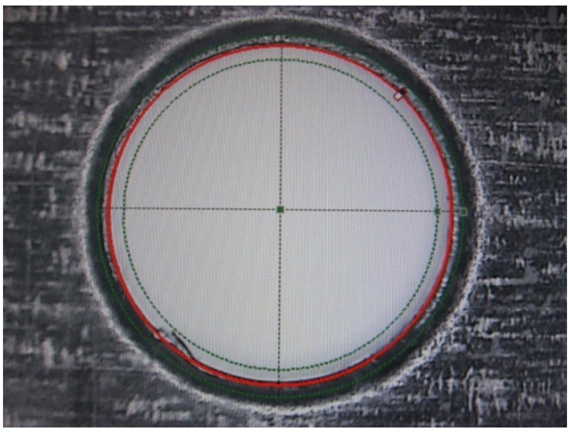


Fig.4. Measuring principle for burr widths based on circle fitting to the burr edges on the CMM.

Table 1. Workpiece material characteristics [10]

Workpiece material – Al99.7Mg0.5Cu-H24						
Chemical composition [wt %]						
Si	Fe	Cu	Mn	Mg	Zn	Ti
0.113	0.16	0.048	0.002	0.476	0.003	0.019
Measured mechanical properties in accordance with EN 10002-1						
Rm [MPa]		Rp0.2 [MPa]		A50 [%]		
150-151		139-141		11-12		

3.1. Workpiece material

The workpiece material employed in this research was wrought aluminium alloy Al99.7Mg0.5Cu-H24. This material is a variation of EN AW 5205-H24 (EN 573-3), or AA 5205-H24 (Aluminium Association of America), where the Mg content has been reduced to 0.5 % instead of 0.8 %. The prefix H24 describes the temper (EN 515), indicating strain hardened and partially annealed material. See Table 1 for chemical composition and mechanical properties of the used material.

4. PRELIMINARY TEST

4.1. Experimental setup

A vertical CNC milling machine (Cincinnati Sabre 750 CNC, 7.5 kW main spindle power) with an electrically driven high speed spindle (NSK Nakanishi HES-BT40 H, max. 50 000 rpm) attached was utilized. The drill used was with split point geometry with reduced chisel edge and polished flutes, 1138/18652.04 from DIXI (Denmark). Drill specifications are listed in Table 2. Drilling thrust and torque were measured by using a table type two-component piezo-electric Kistler 9271A dynamometer with Kistler 5051 charge amplifiers and recorded by a PC acquisition board and LabView 8.0 software. Workpieces of 50x50-2mm were firmly clamped directly on the dynamometer without any support of the drilling exit side (through the center hole in the dynamometer). A 7 % Motorex Swisscool 7755 Aero oil emulsion in water was used as coolant.

4.2. Experimental plan

Influence of cutting speed (see Table 3 with fixed value of feed) and feed per revolution (see Table 4 with fixed value of cutting speed) were evaluated. Due to an insufficient power output of the high speed spindle for higher feeds, test settings in Table 4 were

Table 2. Preliminary drill specifications

No. Flutes [-]	Material/ Coating	Point angle [deg]	Helix angle [deg]	Flutes length [mm]
2	HSS/none	140	13	4

Table 3. Influence of cutting speed on burr formation, preliminary test settings

Setting		1	2	3	4	5
Cutting speed (v_c)	[m·min^{-1}]	80.42	115.61	150.80	185.98	221.17
Feed per revolution (f)	[mm]	0.035				
Spindle revolutions (n)	[min^{-1}]	16 000	23 000	30 000	37 000	44 000
Feed speed (v_f)	[mm·min^{-1}]	560	805	1050	1295	1540

Table 4. Influence of feed per revolution on burr formation, preliminary test settings

Setting		1	2	3	4	5
Feed per revolution (f)	[m·min^{-1}]	0.035	0.064	0.093	0.121	0.150
Cutting speed (v_c)	[mm]	35				
Spindle revolutions (n)	[min^{-1}]	6 963				
Feed speed (v_f)	[mm·min^{-1}]	244	444	644	844	1044

adjusted using the main spindle of the milling machine with lower rotational speed. Coolant was applied during the test using a hand sprayer. Each setting was repeated six times and the drilling order with positions of the holes was randomized.

4.3. Results

The height and the width of the burr were reduced at both entry and exit sides when a higher cutting speed was applied (see fig.5). With higher feed rates, the burr height and width increase on both sides with a more moderate trend up to a certain value where it stabilizes (see fig. 6). Variation in burr dimensions was reduced when higher cutting speed was used, leading to process stabilization. This can be seen from error bars in fig. 5, representing standard deviation of the measured exit burr height from 6 replications for each level of tested cutting speed.

A problem in uniformity of drilled holes occurred in terms of a shiny ring around the perimeter of some holes at the entry side. This was caused by a conical defect at hole entry, causing light reflection in different way than properly drilled holes (see fig. 7). This defect was caused by the drill wandering on the workpiece surface when drilling was initiated with low feed rate. At higher feed rate, this phenomenon was seen to be limited.

5. CLAMPING SYSTEM INVESTIGATION

A vacuum clamping system was constructed to hold the sheet workpiece at place and restriction of room for burr formation at drill exit side. Two NBR (Nitrile butadiene rubber) O-rings having hardness of 70 Shore were used as vacuum seal. These seals were fitted in grooves having rectangular geometry with the workpiece sheet resting directly on them. When vacuum is applied, the O-rings fill in the grooves, ideally leaving no freeboard between the fixture and bottom surface of the workpiece, thus leaving no space for exit burr formation. In order to evaluate the influence of the clamping system, the same drilling conditions, tool, and experimental setting were used

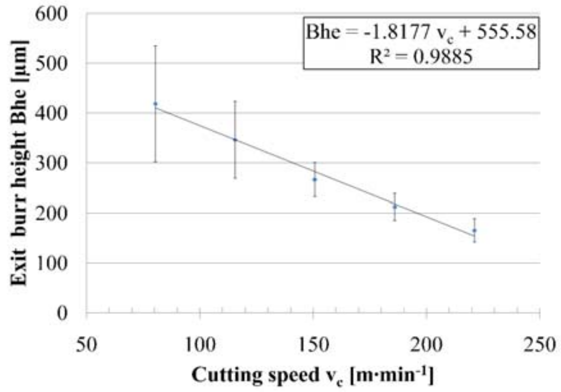


Fig.5. Influence of cutting speed on exit burr height.

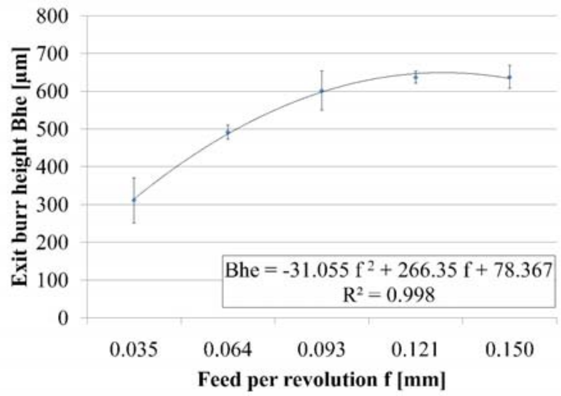


Fig.6. Influence of feed rate on exit burr height.

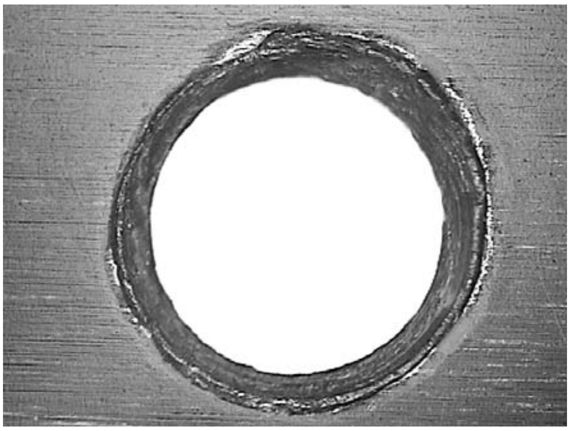


Fig.7. Hole entry defect.

as during the preliminary test. A high vacuum pump Speedyvac ES100 was used as vacuum source. Such setting allowed comparison of exit burrs formed and evaluation of the clamping system with respect to exit burr formation.

5.1. Results

A reduction of about 50 % in exit burr formation was obtained during the test when vacuum clamping was utilized, compared to exit burr formed from the preliminary test with no support of the drill exit side (see fig. 8). It is apparent, from the graph, that the burr height was of a stable value at approx. 250 µm, indicating that the vacuum seal was not compressed enough, leaving this amount of space for the exit burr to form (freeboard between sheet and the fixture).

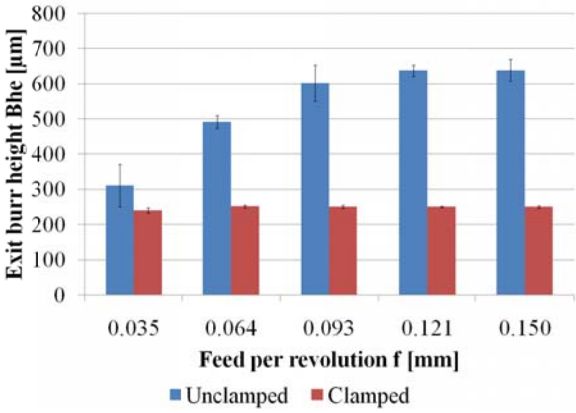


Fig.8. Effect of clamping on exit burr height.

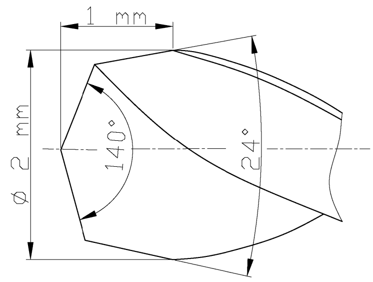


Fig.9. Profile of double cone point drill A.

6. DRILL GEOMETRY INVESTIGATION

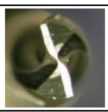
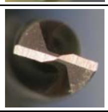
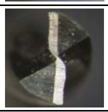
6.1. Experimental setup

A vertical double spindle CNC machining centre (Chiron DZ 12K W high speed plus, 14 kW spindle power) was used during the investigation. Four different drill geometries with fixed diameter of 2 mm were tested and their specifications are listed in Table 5. Drill A was with double cone (chamfered) point geometry (see fig. 9) which from previous research is seen to produce burr free edges at the hole exit in cast iron as workpiece material. Aluminum sheet workpiece was firmly held by a special vacuum clamp fixture with vacuum seal made of soft neoprene rubber fitted in dovetail grooves, ensuring no freeboard between sheet and fixture after clamping. Thrust force was measured by a table type Kistler 9257BA dynamometer and processed and recorded by a PC equipped with DynoWare software from Kistler. A Flood coolant of 7 % water emulsion (HOCUT 795B) was applied during drilling.

6.2. Experimental plan

In order to investigate the burr formation process, and because of the occurrence of errors in visual uniformity of drilled holes, a big amount of drilled holes was required. Therefore, 22 different drilling conditions were tested, resulting in 4 400 holes for each drill tested following a randomized order. Burr measurements were performed only for settings ensuring high productivity - the highest cutting speed of 226 m·min^{-1} and 4 levels of feed rate, f = 0.035, 0.073, 0.125, and 0.190 mm, using the vacuum clamp fixture.

Table 5. Summary of drills tested in tool geometry investigation

Drill point	Tool designation	No. Flutes [-]	Material/ Coating	Point angle [deg]	Helix angle [deg]	Flute length [mm]	Price [DKK]	Drill type/ manufacturer
	Drill A	2	HM Carbide/ none	140/24	30	6	325	180841-1/ TN Slib A/S (Denmark)
	Drill B	2	Carbide/ TiAlN	140	30	12	70	WX-MX-GDS/ OSG (Japan)
	Drill C	2	HM Carbide/ none	140	30	6	325	180841/ TN Slib A/S (Denmark)
	Drill D	3	Carbide alloy/ coated	140	30	10	375	CrazyDrill^{TM}Alu/ Mikron Holding AG (Switzerland)

6.3. Results

The 3-flute drill D required only about 50 % of the thrust force in comparison with 2-flute drills (see fig.10). Due to the lower thrust force exerted, less workpiece material was subject to plastic deformation, resulting in smaller or burr-free edges at hole exit (see fig.11). Double cone point drill A created an excessive entry burr heights 2 to 3 times larger than resulting from other tested drills.

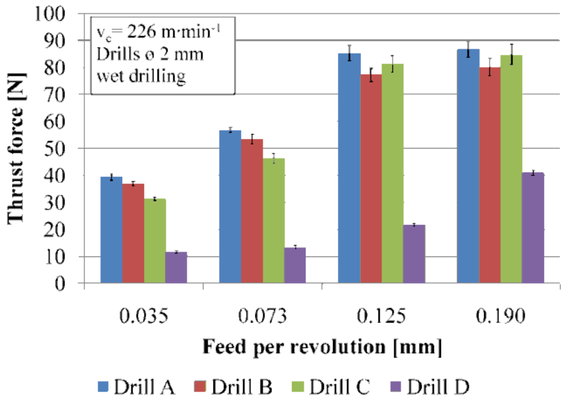


Fig.10. Comparison of drilling thrust force using 4 different drills.

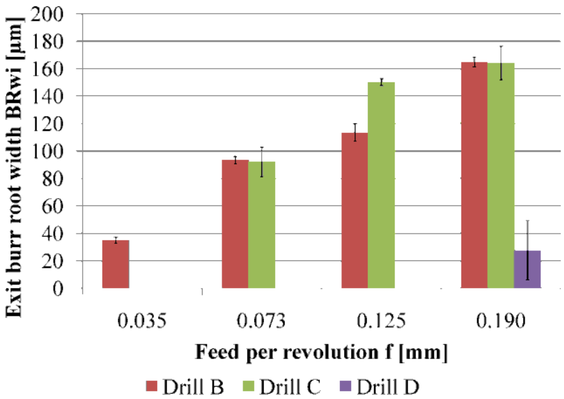


Fig.11. Comparison of exit burr root widths using 3 different drills (Drill A excluded).

6. CONCLUSIONS

An experimental investigation of hole quality and burr formation was performed on drilling 2 mm aluminium alloy sheets using 1.6 and 2 mm drills. Cutting data, clamping conditions and drill geometry were varied and hole quality and burr dimensions analysed.

The overall conclusions from the investigations are:

- Burr reduction with increased speed
- Burr reduction with reduced feed rate
- Conical defect at hole entry can be eliminated by using high feed, short drill length, and drill point warranting good self-centering capability
- Significant reduction of exit burr with properly constructed clamping system

Such an optimized drilling process results in a noticeable production cost reduction.

REFERENCES

[1] Dornfeld, D., Min, S. (2010). A Review of Burr Formation in Machining, In *Burrs – Analysis, Control and Removal*, Springer Berlin Heidelberg, pp.3-11.

[2] Aurich, J. C., at al. (2009). Burrs – Analysis, Control and Removal, *CIRP Annals – Manufacturing Technology*, Vol. 58, pp.519-542.

[3] ISO 13715:2000 Geometrical Product Specifications (GPS) – Technical drawings – Edges of undefined shape, vocabulary and indications, International Organization for Standardization, Geneve, Switzerland.

[4] Gillespie, L. (1974). The measurement of burrs, *SME Technical Paper*, Vol. MR74-993.

[5] Schäfer, F. (1975). Entgraten, Krausskopfverlag, Mainz

[6] Leopold, J., Schmidt, G. (2004). Methods of Burr Measurement and Burr Detection. *VDI – Berichte 1860*, pp.223-229.

[7] Hoang, H., Ko, S. (2010). Burr measurement system for Drilled Hole at Inclined Exit Surface, In *Burrs – Analysis, Control and Removal*, Springer Berlin Heidelberg, pp.157-165.

[8] Alicona Imaging GmbH, [online] [cit. 2011 April 19] http://www.alicona.com/home/products/InfiniteFocus/Infinite Infin-Standard.en.php.

[9] Alicona Imaging GmbH, [online] [cit. 2011 April 29] http://www.alicona.com/home/products/Mex/MeX.en.php.

[10] Alcan Singen GmbH, Alcan specialty sheet, Alcan Singen GmbH, Germany.