Tribology Test Methods and Simulations of the Effect of Friction on the Formability of Automotive steel Sheets

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3 authors:

Sandip Jadhav
Lehrstuhl für Umformtechnik, Montanuniversität Leoben

Martin Schoiswohl
Montanuniversität Leoben

Bruno Buchmayr
Montanuniversität Leoben

Tribology Test Methods and Simulations of the Effect of Friction on the Formability of Automotive Steel Sheets

edited by: **S. Jadhav, M. Schoiswohl, B. Buchmayr**

The light weighting and crashworthiness are the core interest of the automotive manufacturers. To achieve this, different grades of high strength materials are used for the body panel and structural members, but manufacturability of high strength material is a challenging task. The tribology plays a key role in the formability of material and quality of product. Surface roughness of sheet and tooling surfaces, surface coating, lubrication type and lubrication quantity are the fundamental parameters of tribological performance. In order to develop sheet metal parts for automobile, formability tests using experimental devices as well as numerical software tools are used. The prediction accuracy mainly depends on the input parameters. Friction testing at room temperature is performed by draw-bead tests and the formability is measured using Nakajima tests. The effect of different friction coefficients on the results in case of deep drawing is simulated using AutoForm and the effect on the forming limit diagram is discussed in detail.

KEYWORDS: TRIBOLOGY - FRICTION COEFFICIENT - SURFACE ROUGHNESS – LUBRICATION - FORMING LIMIT DIAGRAM

Jadhav Sandip, Schoiswohl Martin, Buchmayr Bruno
Chair of Metal Forming, Montanuniversitaet Leoben, Austria

INTRODUCTION

In recent years manufacturing processes of sheet metal forming have become more challenging due to geometrical complexity, advanced high strength steels (AHSS) und the expectation of high quality products. To overcome these challenges, the sheet metal forming community is continuously working on improvements of the forming processes. It is well known that not only material parameters have a major effect on the deep drawing behaviour, but tribology also plays a key role in metal forming. These tribological effects are usually taken as a given rigid parameter which is mostly given by Coulomb's friction law. The simulations are done using a constant value, which does not describe the real behaviour. Because of this, friction conditions and tribology become an important research area.

In this paper, the effect of friction condition and the dynamic change of the tribological parameters are examined. First, the surface roughness of a sheet metal (DC04) and the friction coefficient during drawing are measured. To compare the results different lubricants like oil, Mo2S and graphite are used. The second task is to measure all relevant parameters. Therefore draw-bead tests and Nakajima tests were done. To see the effect of friction, there are two sets provided. The first set will be tested without lubrication, the second with specific coatings, to lower the friction coefficient.

After the physical simulations, numerical simulation will be done using the software AutoForm. With the support of TriboForm the effect of surface morphology on the dynamic friction change will be simulated as well.

The final part of this paper gives a comparison between physical and numerical simulation and a discussion of the friction effect for manufacturers.

Tab. 1 - Nominal chemical composition of steel sheet DC04 [4]

Chemical analyses of DC04			
C [%]	P [%]	S [%]	Mn [%]
0,00 – 0,08	0,00 – 0,03	0,00 – 0,03	0,00 – 0,04

EXPERIMENTAL SETUP

Draw–bead testing

The Draw-bead test is a widely used method to analyse the friction coefficient during a drawing process with given parameters. The sample is clamped with a known normal Force FN in the lower side of the machine (rigid part), the other end is mounted in the upper moving part (Fig. 1). The clamping force is measured through the whole process as is the movement of the upper part, which moves upwards with a given velocity. The friction force FR is measured by the force which is needed to pull the strip through the clamps. With an evaluation unit exact values of the friction coefficient at every position during this test is calculated. [1]

$$\mu^i = \frac{F_R^i}{F_N^i} \quad [1]$$

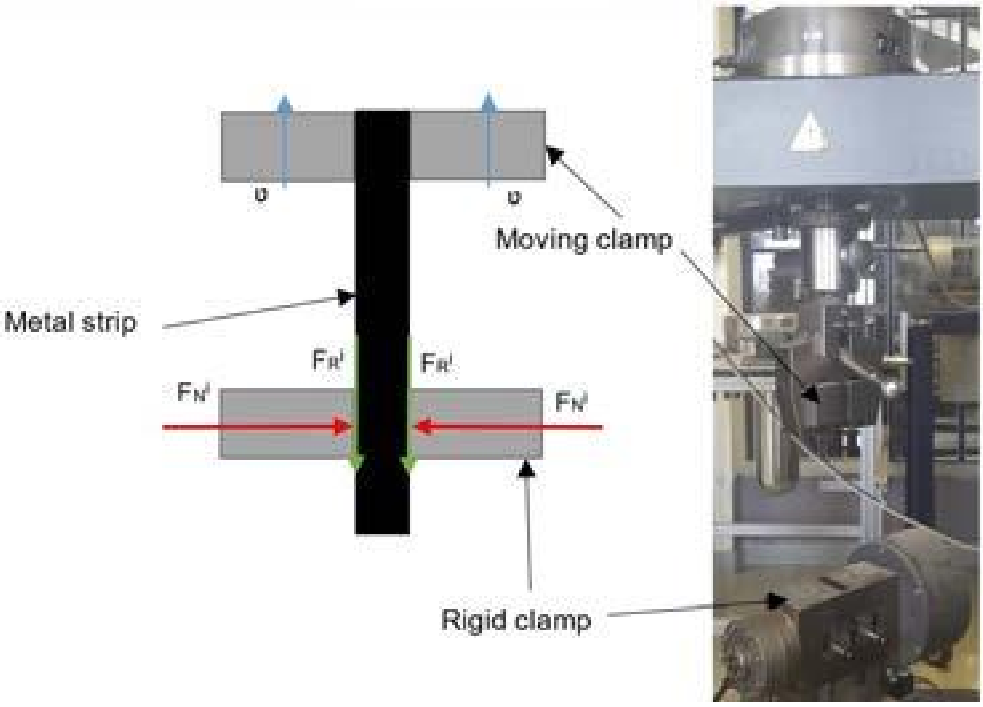
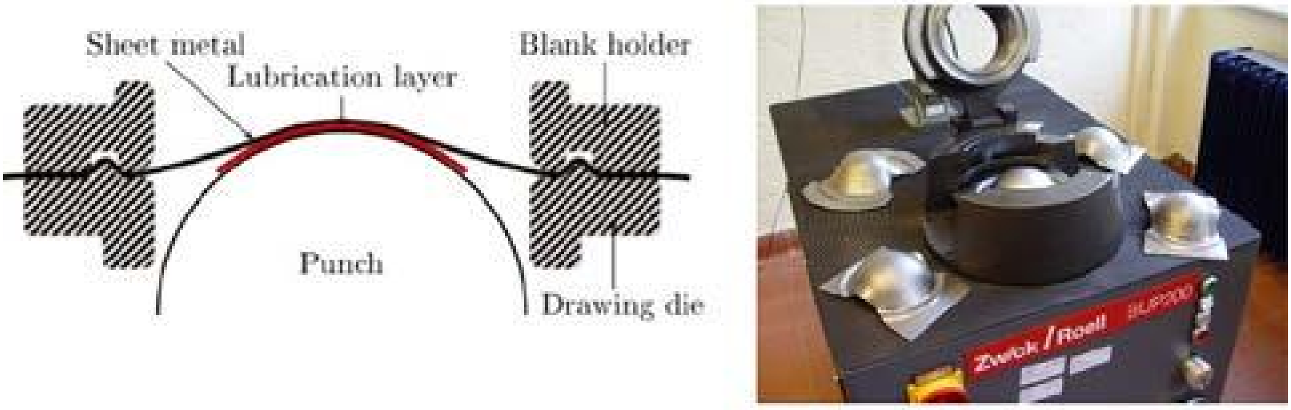


Fig. 1 - a) Scheme of Draw–bead test; b) Real Draw – bead device

Nakajima test

The Nakajima test is based on the deformation of sheet metal blanks with different geometries using a spherical punch [2]. The metal is centrically placed on the drawing die. The blank holder applies a constant blank holding force on the sheet, which is supported by a constant drawbead (Fig.2). After the metal is clamped between the drawing die and the blank holder, a punch moves upwards through the blank. To achieve better results a lubricant layer (foil + oil) is applied between the punch and the sheet metal [3]. The strain path of this drawing process is measured with an optical measurement system which spots points on the metal surface and traces their shift during the test. By plotting the strain rate over a selected length on the surface, major and minor strains are calculated.



a) b)

Fig. 2 - a) Sketch of the clamp and punch used in Nakajima test [3]; b) Real Nakajima testing device

EXPERIMENTAL APPROACH

Surface roughness measurement

Before the experimental tests started, all samples were measured using an Alicona Infinite Focus measurement system. This system measures surface roughness (Fig.3). Roughness has a main effect on the adhesion and wear resistance [5]. Therefore it also has an effect on the spring back and flow behaviour of the material, which has a negative effect on benchmark problems. This effect is caused by the different stress states in the material which occur because of friction (Fig. 9).

For the experimental approach 6 samples for the draw–bead test (Strip_1-6) and 3 samples for the Nakajima test (60_1-3) are provided with a thickness of 1mm (Tab. 2). All specimen are measured along a centrically line in the 0° direction. For the Nakajima test samples with 60mm width are selected.

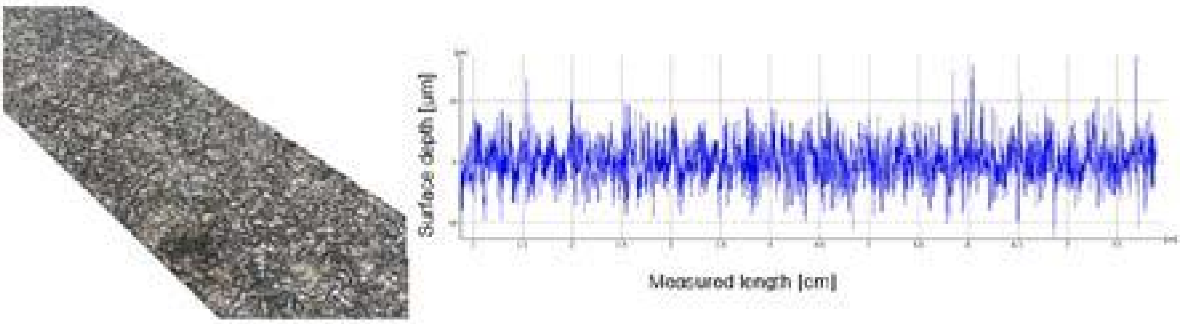


Fig. 3 - 3D measurement and surface roughness along the center line measured with Alicona confocal system

Tab. 2 - Surface roughness of steel strip DC04

Roughness of DC04			
Sample	Ra [µm]	Rz [µm]	Rq [µm]
Strip_1	2,20	21,71	2,82
Strip_2	2,22	20,74	2,85
Strip_3	2,18	21,71	2,81
Strip_4	2,19	19,78	2,78
Strip_5	2,10	17,90	2,66
Strip_6	2,31	21,12	2,95
60_1	2,81	27,52	3,77
60_2	2,48	23,83	3,32
60_3	2,65	23,78	3,40
Average roughness of Strip_1 - 6	2,20	20,49	2,81

The roughness level of the material only varies in a small range (2,10µm – 2,81µm). The average Ra of the stripping test samples is 2,20 [µm]. This data is used for the numerical simulation with the software AutoForm. The tribological part of the simulation is calculated by TriboForm software, which takes into account surface morphologic and a kind of load curve. Using this approach, the coefficient of friction is replaced by a contact model or ultimate collapse load, resp.

Draw–bead test

The samples Strip_1 and Strip_2 are tested without any coating, Strip_3 and Strip_4 are covered with oil (Tonna S3 M68) and Strip_6 and Strip_7 are sprayed with a graphite spray (Graphite Assembly Paste + MoS2). A fixed clamping force (FN) of 2100 N and a testing speed of 8 mm/s is set.

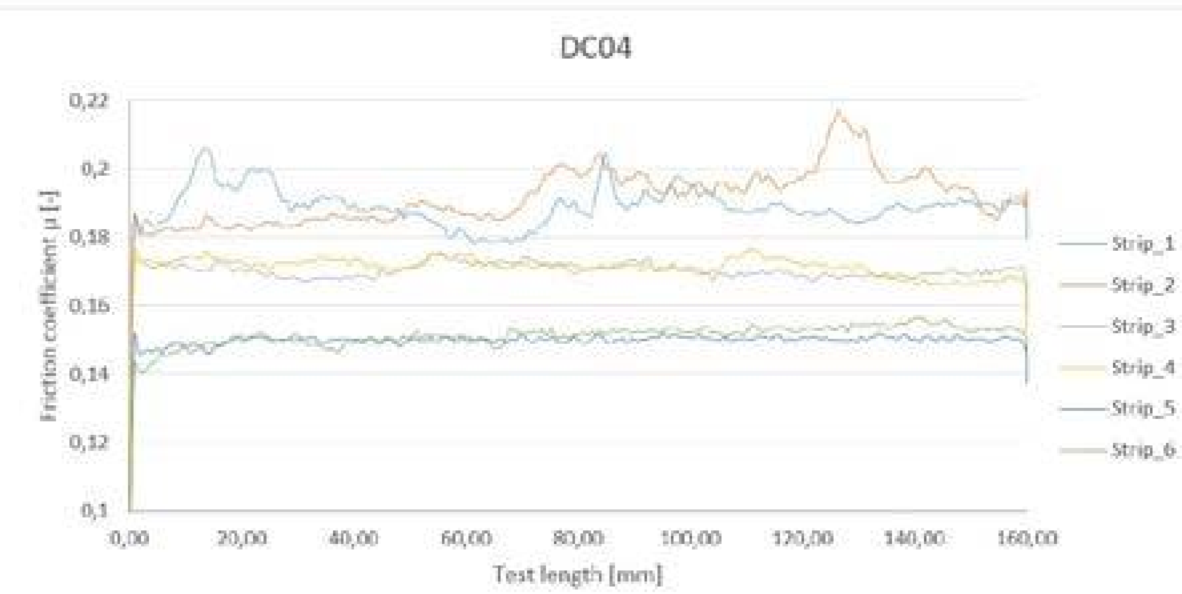


Fig. 4 - Measured results of Draw–bead test on steel strip DC04

Fig. 4 shows the measured results of the stripping test. Average value of friction is 0,19 for uncoated samples, 0,17 for oiled specimen and 0,15 for graphite sprayed steel strips. The uncoated samples Strip_1 and Strip_2 show the highest deviations because of the influence of the surface roughness. Coated samples show a more even behaviour during this test considering the lower influence of the surface roughness and a lower friction coefficient caused by the optimization of the surface between the friction pads and the metal strip.

Nakajima Test

For the Nakajima test the samples are tested without coating and with graphite coating to show the effect of friction. With an ARAMIS system major and minor strain is measured during the deformation caused by the punch. The critical area around the crack is observed. For uncoated blanks the crack does not occur in the middle of the punch as the Nakajima test predicts because of the high friction influence.

Fig. 5 shows the measured results for the Nakajima test. Samples with graphite coating show a better drawing behaviour. In the figure the numbers behind the lubrication type are the tested lines in the area where the crack appears. The Aramis system measures the minor and major strain until short before crack initiation. For evaluation reasons the system uses three parallel lines through this area and predicts exactly the strain path there (Fig. 7).

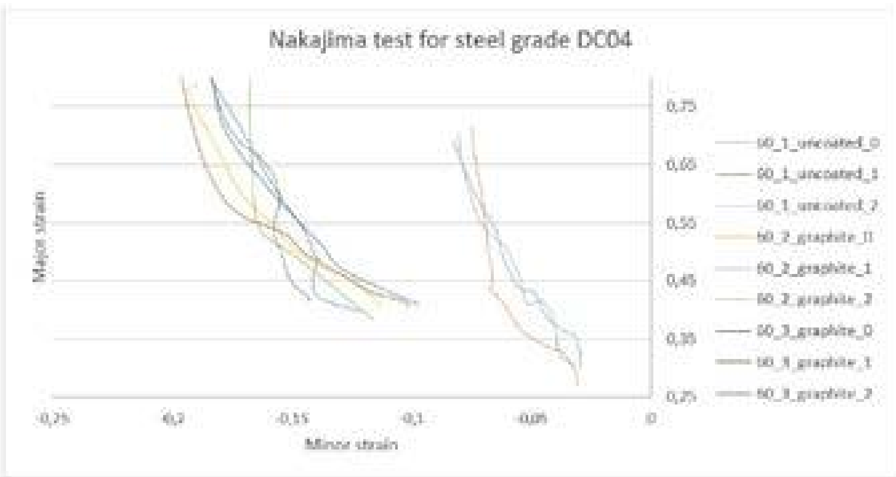


Fig. 5 - Nakajima test for steel strip DC04

For this test, the crack should appear in the middle of the punch, every deviation means an influence of the friction [6]. Also the tested samples show that the crack primary moves from the edge of the punch to its centre by lowering the friction by adding lubrication (Fig 6).

Fig. 6 - Position of the crack. Left without lubrication, right with graphite coating.

Finite Element Simulation

In the finite element (FE) simulation stage, the AutoForm solver is used for the FE simulation purpose. As demonstrated in [7,8], material properties data include hardening, yield surface and material failure. The results from the draw-bead test and the Nakajima test of the experimental study are implicated in the initial stage of FE simulation. With TriboForm, the friction is simulated as similar to the draw-bead test as possible. For the numerical simulation with AutoForm, the geometry of every part from the physical simulation such as punch, blank holder and die is recreated. Also velocity and forces are applied as in the Nakajima test.

Fig 7. shows the results for the simulations with and without coating. The sample with no coating on it, on the left hand side, shows a variation of the appearance of the crack. The picture shows that by reducing the influence of the friction by using lubrications such as graphite or foils, the crack moves to the centre of the sample. For the simulation on the right hand side TriboForm software was used to create a coating which is similar to the Graphite Assembly Paste. By reducing the friction, the flow behaviour gets more stable and as the draw-bead test shows, there is a smoother contact between the surfaces of punch and specimen.

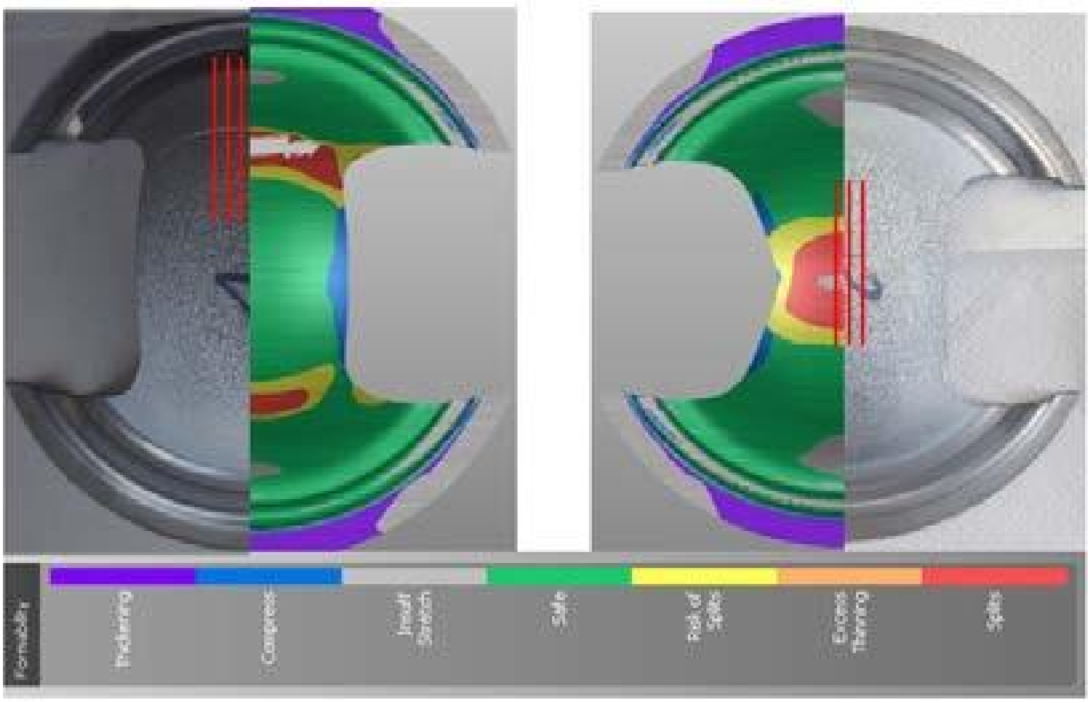


Fig. 7 - Comparison physical and numerical simulation. Left without coating, right with graphite coating.

RESULTS AND DISCUSSION

With lubrication it is possible to achieve a higher major strain path during a forming process without any failure. The lower the friction coefficient the better are the results compared to a simulation or other predictions. Fig. 8 shows the difference of the simulation with a constant Coulomb friction coefficient and the dynamic friction model created with TriboForm. By comparing this result to the physical simulations (Fig. 6), differences in the prediction of the position of the crack can be seen. This deviation is one of the main reasons for misinterpretations of numerical simulations and often leads to costly reworking of tools created by such a simulation with Coulomb's friction law. To avoid this, it is important to know the surface and friction behaviour of every produced part.

The friction has also an effect on the spring back behaviour (Fig. 9). This is caused by the different strain distribution in the material. Better lubrication can lead to a higher amount of insufficient stretching, which causes higher spring back, especially for materials like aluminium. Also this effect can change the position of critical areas by causing different flow directions. Changing lubrication or coatings can be difficult and should be characterized before using them [9].

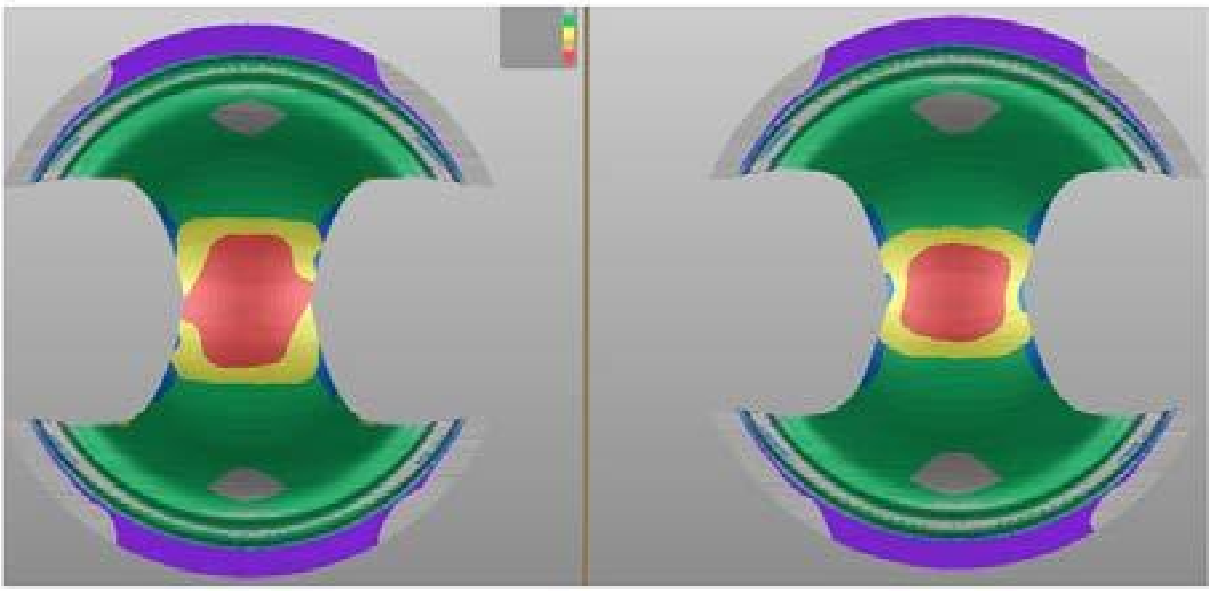


Fig. 8 - Left simulation with Coulomb's friction law, right friction model by TriboForm

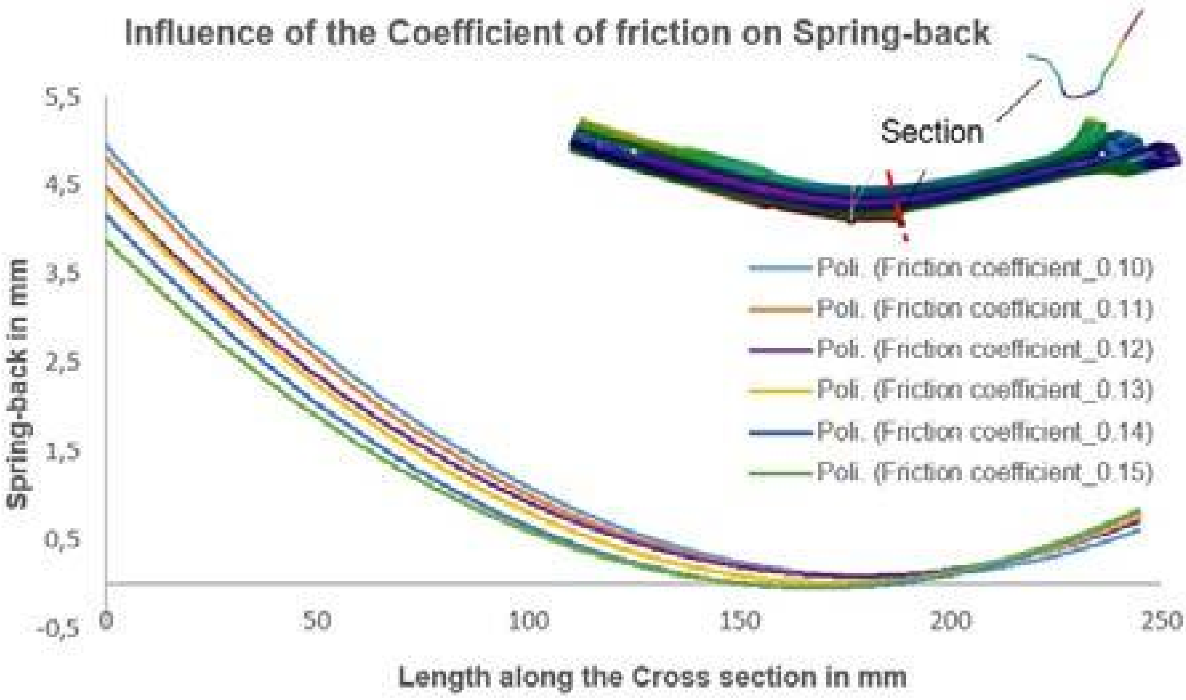


Fig. 9 - Influence on the spring back behaviour caused by friction [9]

OUTLOOK AND FURTHER WORK

Future work will include more variations of lubrication and using different surface roughnesses for the same material. Also materials with higher anisotropy and Young's modulus like Aluminium, 22MnB5 and advanced high strength steels (AHSS) will be considered.

In the draw-bead test variations with foils will be used. By using this test and a foil, the foil is going to tear before any values can be measured. By trying to change forces and friction pads, we try to get rid of this effect.

For the Nakajima test more samples with different geometries will be provided. This variation of geometries can cause problems during the test with other lubrication types than the one used for the laboratory tests which approximates the coefficient of friction to zero. Most of these specimen show cracks out of the area which can be observed with any optical measurement system.

REFERENCES

1] Smith RH: Analyzing friction in the design of rubber products. Taylor & Francis Group, 2008. 7-14

2] GOM optical measurement System; Material Properties: Determination of Process Limitations in Sheet Metal Forming - Forming Limit Diagram, 15.03.2018 (https://www.gom.com/fileadmin/user_upload/industries/flc_fld_EN.pdf)

3] Björklund O., Larsson R., Nilsson L.: Failure of high strength steel sheets: Experiments and modelling, Journal of Material Process Technology 213, 2013, 1103-1117

4] Salzgitter Flachstahl DC04 data sheet; https://www.salzgitterflachstahl.de/fileadmin/mediadb/szfg/informationsmaterial/produktinformationen/kaltgewalztes_feinblech/eng/dc04.pdf, 15.03.2018

5] Schuth M., Buerakov W.: Handbuch Messtechnik - Praktische Anwendungen für Entwicklung, Versuch, Fertigung und Qualitätssicherung. Carl Hanser Verlag GmbH&Co.KG, 2017. 181-183

6] Bergström Y., Ölund S.: The Forming Limited Diagram of Sheet Metals and Effects of Strain Path Changes on Formability: a Dislocating Treatment, Materials Science and Engineering 56, 1, 1982, 47-61

7] Hol,J.; Meinders, V.,T.; Rooij, M., B.; Boogaard, A.,H.: Multi-scale friction modeling for sheet metal forming: The boundary lubrication regime, Tribology International 81, (2015), 112–128

8] Sigvant,M.; Pilthammar,J.; Hol,J.;Wiebenga,J.,H.; Chezan, T., Carleer, B.; and Boogaard, A.,H.: Friction and lubrication modeling in sheet metal forming simulations of a Volvo XC90 inner door, IOP Conf. Series: Materials Science and Engineering 159 (2016), 1-8

9] Jadhav S., Schoiswohl M., Buchmayr B., Applications of Finite Element Simulation in the Development of Advanced Sheet Metal Forming Processes, BHM 163, 3, 2018. 109-118