INVESTIGATION OF COATINGS FRICTION COEFFICIENT USED IN PRODUCTION OF DEEP DRAWN PACKAGING CANS

M. Kršulja[1], P. Roškanin [2], J. Kudláček [2], L. Pomenić[1] and Zlatan Car[1]

[1] University of Rijeka Faculty of Engineering, Vukovarska 58, 51 000 Rijeka, Croatia.

[2] Czech Technical University in Prague, Faculty of Mechanical Engineering, Technická 4, 166 07 Praha 6, Czech Republic

Keywords: friction, sheet metal, deep drawing, tribology, coating, lacquer

Abstract. In technology of deep drawing of cans the use of lubrification oil has been replaced by coating finishes accordingly to packaged products. Wear of added coating can occur at edges and small radii where the average added coatings due to processing thinning reduces its size. Friction influences deep drawing parameters. If the optimal ratio can be established between coating selection, friction and deformation forces a better control and insight in deep drawing technology is possible. Investigation of friction coefficient for Gold lacquer, Overprint varnish and Alu pigmented lacquer for material TH 550 E2.8/2.8 FS 0.155 mm has been calculated with tribometer TOP 3.

Introduction

Sheet metal forming (SMF) technology uses sheet material that is plastically deformed in two dimensions (the thickness of the sheet is more or less constant) with the possibility of significant elastic recovery or spring back. Each metal forming process has its own characteristic features in terms of tooling and material flow. In Fig. 1 some products of thin sheet that ranges in thickness from 0.15 mm until 0.49 mm metal forming are shown.

Fig. 1 The products made from thin sheet metal forming taps and cans. [1]

Common features of SMF processes are the use of initially flat sheet material cut into an optimized shape (the blank), a punch to transmit the energy needed for the mechanical work, a die that directs the material flow during the process, a blank holder, which controls undesired material flow and wrinkles, and draw beads that are used to restrict material flow. SMF processes are suited for mass production applications and the products are processed, fully automated, in large volumes with the help of industrial presses. Forces that occur in deep drawing range from pneumatic 500 kN to 200.000 kN for Hydraulic presses, for mechanical presses strokes range up to 2000 strokes per minute [2, 3]. In order to control material flow during the deep draw process and surface quality of the formed products adequate lubrification condition need to be obtained. Poor lubrication or coating [4-6] can result fracture that leads to scrap (Fig. 2) due to high friction that limits the desired material flow. One of observed occurrences with low friction forces is pronounced wrinkling and on the other side if friction is too high the material can break. Therefore the friction is a very important parameter of the die construction that needs to be optimized depending on the die construction and forces included in process, and needs to be incorporated in virtual programming of production technology [7].

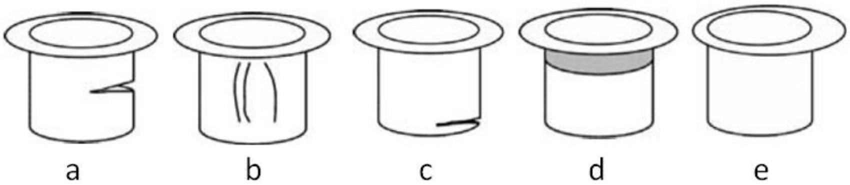

Fig. 2 Poor lubrification influences a) cracks, b) sec. wrinkle/pucker c) crack near bottom d) drawing marks, e) asymmetrical flange [2]

In technology of deep drawing of cans the use of lubrification oil has been replaced by coating finishes (tin layer combined with an organic coating). Coating finish has to have specific properties the capability to provide for adequate flow during the deep draw process and surface quality. Primary function of coating finish in packaging industry is to have adequate durability depending on the ph properties of packaged product. Coating has to resist the temperature of sterilization, transport damages and prevent interaction between product and environment. As the coating is applied before deep drawing process it has to adequately survive the deformation process. In this paper investigation of friction coefficient is conducted for the deep drawing process for material TH 550 E2.8/2.8 FS 0.155 mm that is covered with lacquer and cured for 20 minutes at the temperature of 200 °C. TH 550 is used for shallow deep drawing parts such as taps and covers of cans, where designation E2.8 defines the tin coating of 2.8 g/m^3, while the designation FS defines fine stone surface Ra = 0,25–0,45 µm, and proof strength Rp of 550 ± 50 MPa.

Coating

Coating is deposited on the sheet metal plate in accordance to shape and desired layer thickness of selected material, and then cured from 8 to 20 minutes at a temperature of 175 ° C to 225 °C. For sheet metal deep drawing process typical friction factor that is obtained by lubrification is $\mu \approx 0.17$, [3]. This factor was obtained by combination of Gold lacquer lr and mineral oil Ondina 15. Ondina 15 oil is of high purity and is used in the food and beverage industries. Its manufacturer is familiar company Shell. This oil is tasteless, colourless and odourless because of its extremely high purity it is also is used in medicine (medical white oil). Viscosity is 15 mm^2/s (at 40 °C), the density of 850 kg/m^3, flash point at 200 °C and the solidification point -15 °C. The basic purpose are tin sheets and ECCS where requiring high corrosion resistance and extra deep-drawing, which ensures smooth coating based on epoxy phenol. Without the lubrification and coating the hardened steel sliding on tin has the friction coefficient of $\mu = 0.17$ [3], however without the lubrification or coating in current deep drawing process material fractures. Additionally cast iron sliding on tin the friction factor has friction coefficient of $\mu = 0.32$ [4]. This proves that not only the friction factor is important but also the capability of lacquer to contain and regulate material flow. Beside Gold lacquer Alupigmented Lacquer and Overprint varnish were tested and their friction coefficients compared (Table. 1).

Table 1 Laquer information

Lacquer	Description	Viscosity
Gold lacquer	Color that resembles gold, GL-79-5.	110 ± 5 mm^2 / s (at 20 °C) and the flash point is 37 °C
Alupigmented Lacquer [5]	Homogeneous opaque film of silver-grey colour.	(4,000±0,015) mm at t° = 20,0 ± 0,5 °C: in the range of 60-140 sec.
Overprint varnish [6] Miraglaze™ 8909 base E	overprint varnish base, wet-on-wet and wet-on-dry. Varnish with wax and no driers.	10 at 23 °C at 25 s^{-1} (Pa.s)

Experimental setup

The friction was determined using a Tribometer TOP 3 (Fig. 3). TOP 3 is an acronym of translation oscillation movement. The settings of the tribological tests are summarized in the Table 2. Friction contact was realized by specimen´s pair - tablet and slab which demostrate a square contact. Friction contact was burdened with a load of 4 kg (~ 40 N force). Slab specimens were made from thin metal plate with special coating (Gold lacquer, Alupigmented Lacquer, Overprint Varnish). Tablet specimens were made from high strength steel 41Cr4. All the specimens were tested for the same time due to comparison of weight losses (Table 3). After 10 minutes it has been found that the main area of coating was removed and maximal test time of 10 min was determinated. This time corresponds to a distance of 67 meters. Dynamics of movement was established to a 35 cycles per 1 minute, where 1 cycle = length of 2 x 0.095 m = 0.19 m. All the friction results are enclosed in Table 3 - 5. Weight of tablets and the slabs were measured with an analytical balance Mettler H64 and analytical balance Ohaus explorer pro.

Table 2. The tribological test summarization.

FUNCTIONAL PAIR			TEST SETUP						
Specimen´s Marking	Slab	Tablet	Load [N]	Theoretical Pressure [N.mm^{-2}]	Friction Trajectory [m]	Operation Time [min]	Dynamics [cycles per minute]	Sampling Rate [Hz]	Test Condition
A1	Alupigmented Lacq.	Steel 41Cr4	40	0,13	67	10	35	250	dry friction
A2	Alupigmented Lacq.	Steel 41Cr4	40	0,13	67	10	35	250	dry friction
A3	Alupigmented Lacq.	Steel 41Cr4	40	0,13	67	10	35	250	dry friction
O1	Overprint Varnish	Steel 41Cr4	40	0,13	67	10	35	250	dry friction
O2	Overprint Varnish	Steel 41Cr4	40	0,13	67	10	35	250	dry friction
G1	Gold Lacq.	Steel 41Cr4	40	0,13	67	10	35	250	dry friction
G2	Gold Lacq.	Steel 41Cr4	40	0,13	67	10	35	250	dry friction
G3	Gold Lacq.	Steel 41Cr4	40	0,13	67	10	35	250	dry friction

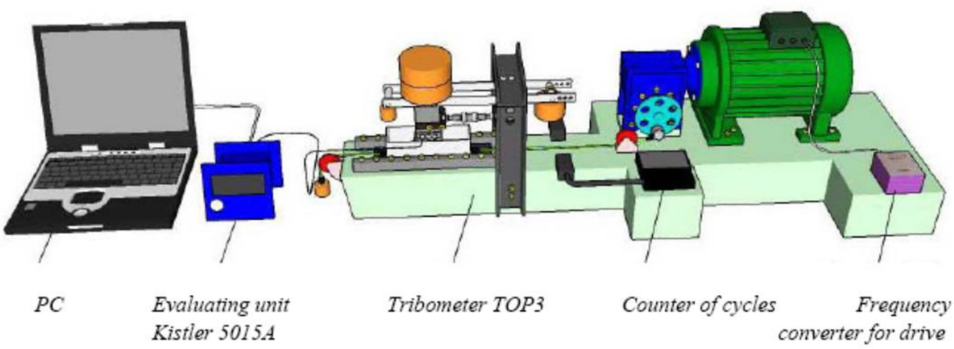

Fig. 3 Tribometer TOP3 with necessary components.

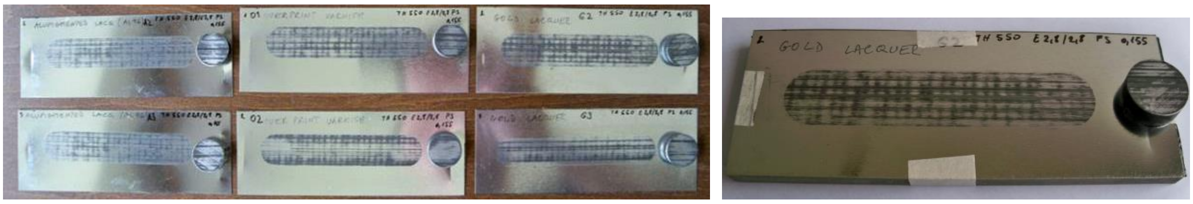

Fig. 4 Test specimens after testing: tablet - Ø20 h11 mm, h=8 mm; slab - 135 x 50 x 8 mm

Table 3. Roughness of used tablets

ROUGHNESS OF TABLETS						
No of measurement	1.	2.	3.	4.	5.	**Mean**
Ra [μm]	0.12	0.12	0.09	0.11	0.10	0.108
Rz [μm]	0.78	0.86	0.61	0.69	0.67	0.722
Rq [μm]	0.15	0.16	0.11	0.14	0.13	0.138

Table 4. Weight losses and mean weight losses (Note: Minus symbol (tablet) means the transfer of coating from slab to the tablet surface.)

WEIGHT LOSSES COMPARISON				
Marking	**Specimen**	**Weight [g] Before Test**	**Weight [g] After test**	**Weight loss [mg]**
Alupigmented Lacquer				
A1	Slab	8,43783	8,43522	2,61
	Tablet	18,49231	18,49266	-0,35
A2	Slab	8,28997	8,28789	2,08
	Tablet	18,53013	18,53071	-0,58
A3	Slab	8,36417	8,36162	2,55
	Tablet	18,87630	18,87660	-0,30
Overprint varnish				
O1	Slab	8,37600	8,37306	2,94
	Tablet	18,50916	18,50977	-0,61
O2	Slab	8,37664	8,37466	1,98
	Tablet	18,64923	18,64964	-0,41
Gold Lacquer				
G1	Slab	8,19132	8,18831	3,01
	Tablet	18,80400	18,80455	-0,55
G2	Slab	8,37470	8,37188	2,82
	Tablet	17,51026	17,51068	-0,42
G3	Slab	8,41572	8,41449	1,23
	Tablet	18,86667	18,86690	-0,23

MEAN WEIGHT LOSSES		
Coating type	**Specimen**	**Mean Weight loss [mg]**
$\mathbf{A_{mean}}$	Slab	2,41
	Tablet	-0,41
$\mathbf{O_{mean}}$	Slab	2,46
	Tablet	-0,51
$\mathbf{G_{mean}}$	Slab	2,35
	Tablet	-0,40

Table 5. Results of friction coefficients and its time development and mean coefficients on the start/end of tribological test

RESULTS OF FRICTION COEFFICIENTS AND ITS TIME DEVELOPEMENT				
Specimen´s Marking	**Time period for μ calculation**			
	20 - 40 s (after start)		**560 - 580 s (before end)**	
	μs [-]	**μd [-]**	**μs [-]**	**μd [-]**
A1	0,4432	0,3992	0,6120	0,5678
A2	0,4080	0,3638	0,5846	0,5654
A3	0,4286	0,3335	0,5720	0,5195
O1	0,4365	0,3900	0,6403	0,5615
O2	0,4374	0,3759	0,5581	0,5124
G1	0,4635	0,4252	0,6336	0,5931
G2	0,4194	0,3541	0,6193	0,5690
G3	0,2216	0,2204	0,6163	0,5564

RESULTS OF MEAN FRICTION COEFFICIENTS				
Specimen´s Marking	**Time period for μ calculation**			
	20 - 40 s (after start)		**560 - 580 s (before end)**	
	μs [-]	**μd [-]**	**μs [-]**	**μd [-]**
$\mathbf{A_{mean}}$	0,4266	0,3655	0,5895	0,5509
$\mathbf{O_{mean}}$	0,4370	0,3830	0,5992	0,5370
$\mathbf{G_{mean}}$	0,3682	0,3332	0,6231	0,5728

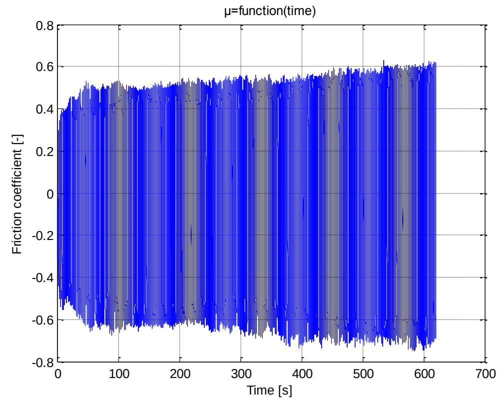

Fig. 5 Example for test A1 Alupigmented Lacquer - results of total test time

A1 **Time 20 - 40s μs= 0,4432 μd= 0,3992** **A1** **Time 560 - 580s μs= 0,6120 μd= 0,5678**

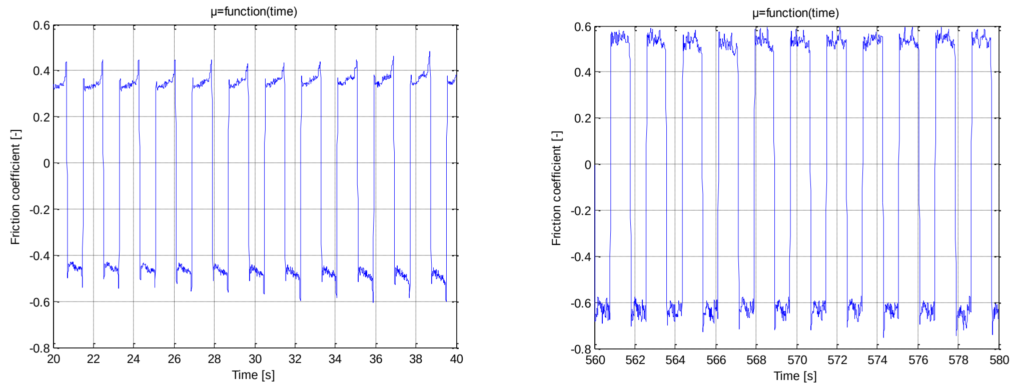

Fig. 6 Example for test A1 Alupigmented Lacquer results from 20 to 40 seconds and a period of 560 to 580 seconds

Conclusion

Tables 3, 4 and 5 show the results of weight losses and the results for friction coefficients for tested materials - Alupigmented Lacquer (A), Overprint varnish (O) and Gold Lacquer (G). The static coefficient of friction is indicated as the μs. Dynamic coefficient of friction is indicated as the μd. Mean values of all coatings have quite the same range. It can be assumed that the wear of coatings – weight losses will be higher in real process due to higher load exposed on the coating´s surfaces. A very important fact is the quickness of deep drowing forming process. It means even the coating will be exposed to higher pressures there will be much less time (trajectory) to wear process. There are two values of friction coefficients in the table 5. First period was taken in time interval from 20 to 40 seconds. The friction coefficient was calculated from the 20 s interval after the tribological test has started. Second period was taken in time interval from 560 to 580 seconds just in the 20 s interval before the test ended. Comparison of friction coefficients in both periods give us information about the coating durability in the time. The most suitable for deep drawing process according the obtained results is the gold lacquer as the friction coefficient for it was the lowest μs=0.3682, μd=0.3332. In modern processes tin cans [2] are produced without addition of oil, and cans process have shown good formability. Future researches will include Finite element simulation [7] based on obtained friction coefficient for deep draw forming and for incremental metal forming, and higher testing loads for better prediction of real factory conditions.

Acknowledgements

The authors would like to acknowledge the support provided by the National CEEPUS Office of Croatia and National CEEPUS Office Czech Republic, which helped the research through mobility in the frame of the CEEPUS II HR 0108 project.

References

[1] Private documents MGK-pack, www.mgk-pack.com, 2011.
[2] Handbook of Lubrication and Tribology, Volume 1, Application and Maintenance, Second edition, International Standard Book Number-13: 978-0-8493-2095-8 (Hardcover) 2006 by Taylor & Francis Group, LLC.
[3] Branimir Barišić, Analiza pojave Ludersovih traka u procesu izrade proizvoda iz tankostijenog lima, Doctoral thesis, mentor: Prof. Goran Cukor, Rijeka 2005.
[4] ROYMECH – friction parameters, http://www.roymech.co.uk/Useful_Tables/Tribology/co_of_frict.htm, 2012.
[5] Khimlex - Varnish-and-lacquer materials for can coating , http://www.khimlex.ua/en/products/varnish/7.html, 2012.
[6] Varnish-and-lacquer materials for can coating, http://www.lawter.com/uploads/pdfs/Lawter_EU_Inks_2012.pdf, 2012
[7] Božek, P. - Mihok, J. - Barborák, O. - Lahučký, D. - Vaňová, J.: New strategies of virtuality in programming of production technology, In: Annals of DAAAM and Proceedings of DAAAM Symposium. - ISSN 1726-9679. - Vol. 20, No. 1 Annals of DAAAM for 2009 & Proceedings of the 20th international DAAAM symposium "Intelligent manufacturing & automation: Focus on theory, practice and education" 25 - 28th November 2009, Vienna, Austria. - Vienna : DAAAM International Vienna, 2009. - ISBN 978-3-901509-70-4, s. 0403-0404.