FAILURE OF COATINGS OF TINPLATES

Emil Spišák[1)], Miroslav Džupon[2)], Janka Majerníková[1)], Emília Spišáková Duľová[3)]*
[1)] *Technical University of Košice, Faculty of Mechanical Engineering, Department of Technology and Materials, Košice, Slovak Republic*
[2)] *Slovak Academy of Sciences, Institute of Materials Research, Košice, Slovak Republic*
[3)] *University of Economics in Bratislava, Faculty of Business Economy with seat in Košice, Slovak Republic*

Received: 01.07.2015
Accepted: 08.09.2015

**Corresponding author: e-mail: emil.spisak@tuke.sk, Tel.: +421 55 6023502, Department of Technology and Materials, Faculty of Mechanical Engineering, Technical university of Košice, Mäsiarska 74, 040 01 Košice, Slovak Republic*

Abstract
The goal of the contribution was to perform the research about the way of failure of tin coatings and their causes and about behaviour of tin coatings at the limit states of deformation. The work shows that in the maximum plastic strain area the failure of tin coating was mainly due to transversal cracks without separation of the coating particles and decohesion at the coating-substrate interface. As an additional tin coating quality test, it would be advisable to include qualitative EDX analysis of tin coating in the area of uniform and maximum plastic strain of the surface of test specimens after a uniaxial tensile test.

Keywords: Coatings, Tin Plate, Corrosion, Mechanical Properties.

1 Introduction

The application of thin steel packaging sheets is aimed mainly to the food industry for the manufacturing of packaging and food cans. One of the strategic trends in the production is reduction of the thickness from the original 0.24 mm to current 0.14 - 0.18 mm, application of extremely thin layers of tin coating while maintaining or increasing its protective properties, increasing of durability and safety of packaging materials. There are relating changes of the mechanical and technological properties. The basic criteria that thin tin plate has to meet are excellent workability, high resistance to the corrosion effects of the environment, it is exposed to during a given period of time. The most common treatment of packaging sheets is the sheet metal forming technology. The most of the sheets are processed by drawing on the draw pieces of different shapes - round, square, oval. During this technological process sheets are exposed to the plastic strain in a way that the resulting pressing is free from defects and failure of the integrity of sheet and without damage of the protective coating of tin [1,2].
In the place of total failure of integrity of the tin coating the packaging sheet corrodes [3-5]. Tin coating is then the protection of the packaging sheet only if the coating is absolutely free from defects [6,7]. When the compactness of coating is damaged there arises macroscopic corrosive component and the packaging sheet corrodes more intensively than the packaging sheet without coating. Use of packaging sheets with tin coating is common particularly in the manufacturing of packaging for canning of food. Environment of canned food is made of the weak organic acids [8].

DOI10.12776/ams.v21i3.590 p-ISSN 1335-1532
e-ISSN 1338-1156

If there are any inhomogeneities in the microstructure of packaging sheet, that create two or more phases, the defects on the surface of packaging sheet or different areas with intensive plastic strain, then in the case of failure of integrity of the tin coating there is condition for the formation of corrosive micro-components. Plasticity of tin coatings depends on the factors such as size of grain, crystallographic orientation, temperature and phase structure of intermetallic layers. After an exhaustion of plasticity of the coating there comes its failure [9-11], for example: by separation of particles of coating, which dimensions are smaller than thickness of the coating; by failure of the coating by decohesion of particles at the coating-substrate interface while the dimensions of separated particles is comparable with the thickness of the coating; by failure of coating in the result of attachment of separated particles of coating on the surface of pressing tool, where adhesively attached particles cause further failure of the coating; by failure of coating by transversal cracks without the separation of particles of the coating [12,13].
Systemic and complex approach towards the solution of problems of pressing technology from the view of tribological processes includes also the research of relation of tribological pair: tool - material in the connection with applied coatings.
According to contemporary knowledge of the localization of plastic deformation on macro and micro level, it can come to the change of friction during the processing of thin tin sheets, by drawing [13-15]. With the influence of pressure between processed sheet and active parts of the tool, it often leads to the affinity of the tin coating and the tool, which can later lead to the change of friction during the process of pressing and so to the growth of tensile force. The increase of tensile force and the change of friction create conditions for the formation of local plastic deformations on the processed material. In these locations there is a significant decrease of the corrosive resistance of tinplate. Layer of coating on the tool should decrease the affinity of tin and Fe (preventing them from attaching) and so the process of drawing should be more stable (so it does not come to such a significant change of frictional ratios in the tool).
The goal of the contribution was to get the information about the way of failure of tin coatings and their causes and about behaviour of tin coatings at the limit states of deformation. And that are an important characteristics for the selection of an appropriate system of coating of pressing tools for different combinations of the sheets processed on the surface (zinc coated, tinned) and the sheets on the base of an alloy of aluminum and morphology of their surface.

2 Experimental material and methods

Thin packaging sheets were made from killed continuously cast steel. In the experimental group there were twice reduced electrolytically both sides tinned thin packaging sheets with thickness of 0.18mm, processed by technology of continual annealing with inbuilt artificial ageing at the temperature of approximately 450˚C. Chemical composition of used steel sheets is in harmony with the recommended chemical composition of material (**Table 1**).

Table 1 Chemical composition of the experimental material [wt. %]

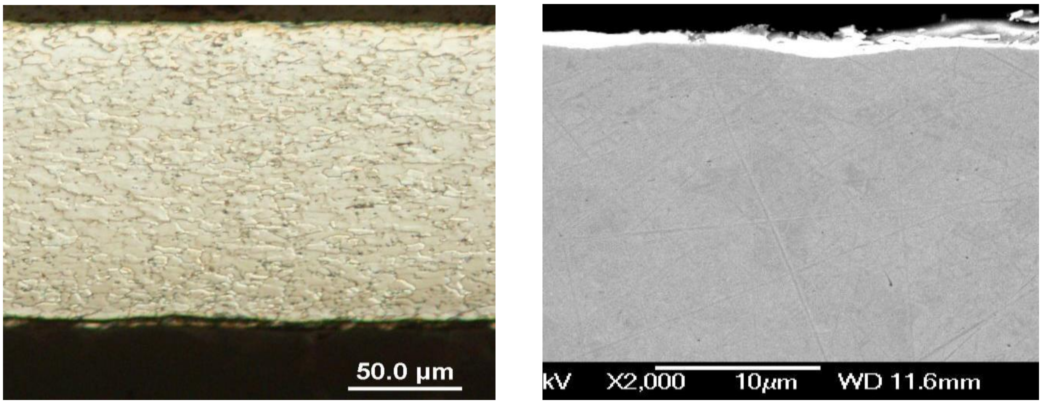
C	Mn	Si	P	S	Al	Cu	Ni	Cr	Mo	Ti	V
0.075	0.130	0.022	0.014	0.002	0.065	0.030	0.005	0.009	0.013	0.002	0.009

Mechanical properties were determined on standard specimens for uniaxial tensile static test by standard STN EN ISO 6982-1. Damaged tin coatings were analysed with scanning electron microscope JEOL JSM-7000F.

DOI10.12776/ams.v21i3.590 p-ISSN 1335-1532
e-ISSN 1338-1156

3 Results and discussion

Microstructure of thin packaging sheets was ferrite-cementite, average thickness of electrolytically excluded tin coating was 1 - 1.3 μm and the weight of tin coating was 1 - 2g/m^2 (**Figs. 1a, 1b**). With uniaxial tensile test there were set basic mechanical properties: yield stress was in the interval from 422 to 518 MPa, ultimate strength was from 420 to 511 MPa. At the elongation of A_{50} there was registered quite large dispersion of values from 0.1 to 22.3% [10]. Reaction of coated steel sheets to the process of forming in the matter of material is the function of microstructure of substrate and coating. The critical point of coated materials is the boundary between the substrate and the coating.



a) b)

Fig. 1 Microstructure of packaging sheet (a). Detail of tin coating (b).

Structure and properties of the coating are modified by the technological process of electrolytic tinning. During the pressing of tin coated sheets these coatings are generally exposed to multi-axial mechanical stress. At the limit states of mechanical stress and strain it could lead to their mechanical damage [16-20]. For the study of ways of the integrity failure of tin coating there were used specimens after the uniaxial tensile test.

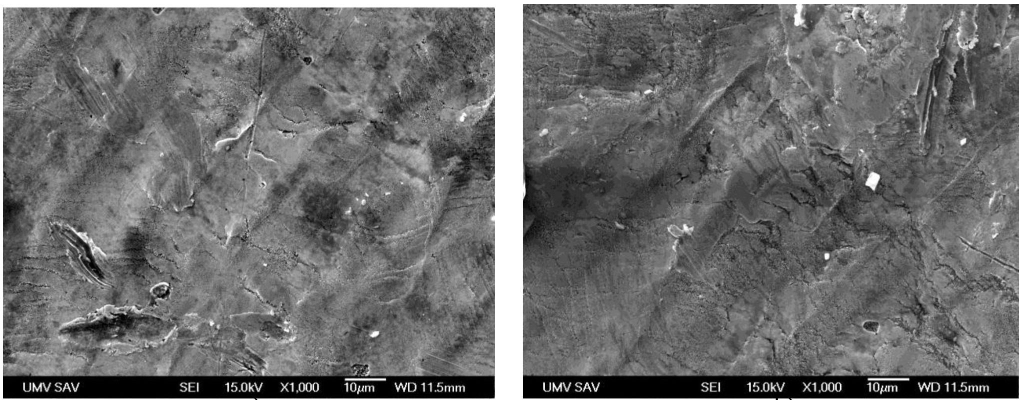
On the testing specimens there were locations with the different level of plastic strain, which differed in the magnitude of measured elongation. On the specimens with the low elongation (<2%), localization of plastic strain predominated, which was visible on the surface in the form of several slip lines. In one of the slip planes it later came to the disruption of specimen, without the plastic strain in the measured length of the specimen. On the specimens with the higher elongation (<5%), there were visible plastically deformed locations and also plastically undeformed locations.

There were areas with different level of plastic strain on the testing specimens: an area with uniform plastic strain; an area around the neck where the plastic strain was located and an area of fracture of packaging sheet with a maximum located plastic strain. In this case the steel material of packaging sheet was the support panel of the coating and by that there was activated various level of plastic strain in the coating.

- Tin coating in the area of uniform plastic strain after uniaxial tensile test was free from failure of the compactness of surface. There were isolated zones on the surface where the coating was damaged with transversal cracks without the separation of particles and without decohesion at the coating-substrate interface (**Figs. 2a, 2b**).

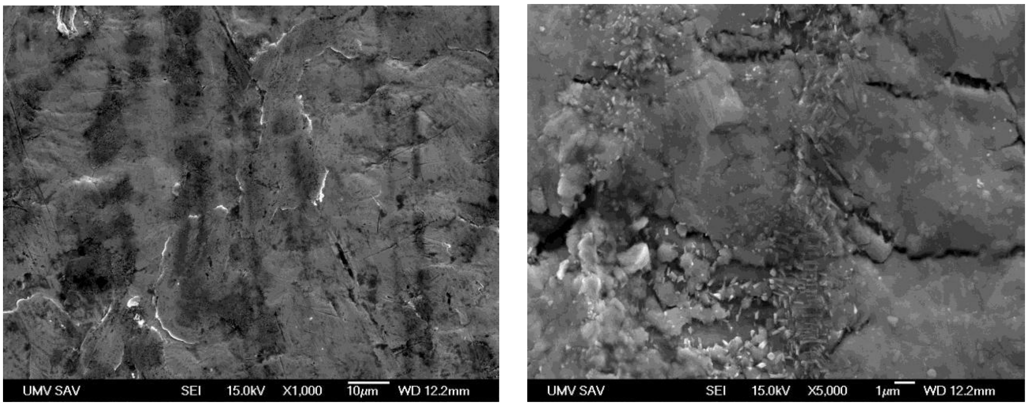
DOI10.12776/ams.v21i3.590 p-ISSN 1335-1532
e-ISSN 1338-1156

- In the area of uniform plastic strain around the neck there was observed a failure of the coating with transversal cracks with dimension of cca 10 μm with a partial separation of particles of the tin coating (**Figs. 3a, 3b**). Tin coating, in this area, did not completely cover the surface of the packaging sheet.
- In the area of maximum plastic strain there was a ductile failure with a lot of dimples (**Fig. 4a**). On the surface of packaging sheet there was an uncompleted tin coating (**Fig. 4b**), the failure of integrity of the tin coating in this area was caused by fragmentation of the coating. On the boundary of the substrate and the coating there was not observed any decohesion of the tin coating. Dimension of the separated particles of the surface was comparable to the thickness of tin coating (**Fig. 4b**).



a) b)

Fig. 2 Tin coating in the area of uniform plastic strain (a), (b).



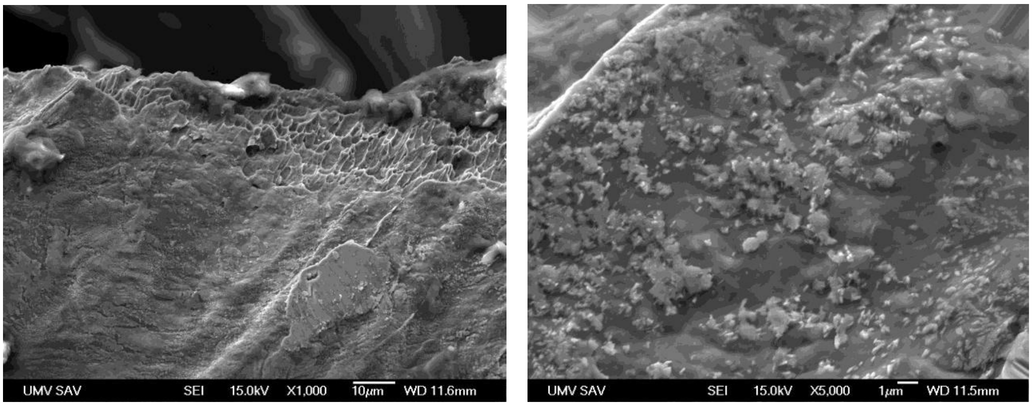
a) b)

Fig. 3 Tin coating in the area of uniform plastic strain around the neck (a). Detail of failure of the coating with transversal cracks with partial separation of particles of the coating (b).

With qualitative EDX microanalysis there were detected the areas of surface without the protective tin coating (**Figs. 5a, 5c**). The coating on the tensile side was being brittle frailly damaged with the creation of transverse cracks, only in the way that damaged segments of the coating did not separate from each other.

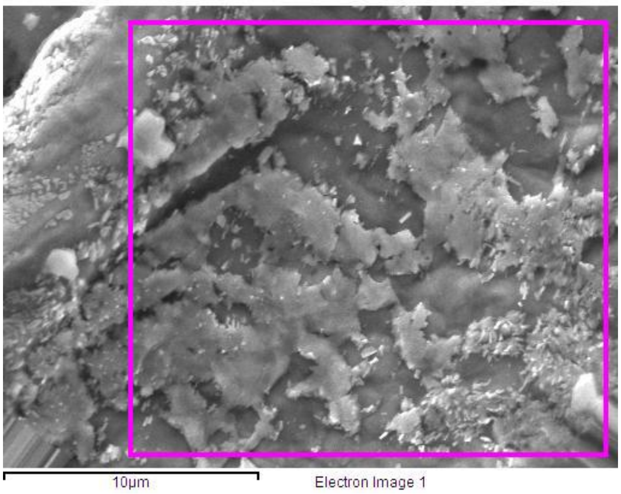
DOI10.12776/ams.v21i3.590 p-ISSN 1335-1532
e-ISSN 1338-1156

The goal of this contribution was to obtain a piece of knowledge about the way of failure of tin coatings and about their behaviour during strain limit states. The coating is an effective protection of packaging sheet only if it is compact and free from defects. In the environment of canned food, on the packaging sheet with damaged tin coating, there are conditions for the formation corrosive components. In this contribution, it was proved that in the area of maximum plastic strain, the tin coating was failure mainly due to transversal cracks without the separation of particles of the coating and without the decohesion at the coating-substrate interface. Uniaxial tensile test is the necessary test of the quality of tin packaging sheets. If we look at the simple preparation of specimens, it would be appropriate to include, as an additional test of quality, the qualitative EDX analysis of the tin coating in the area of maximum plastic strain on the surface of testing specimens after the uniaxial tensile test.



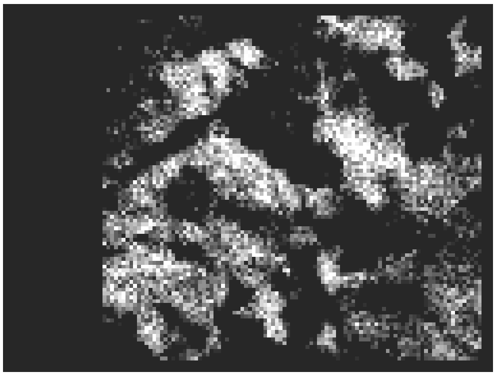
a) b)

Fig. 4 Ductile failure with a lot of dimples in the area of maximum plastic strain (a), detail of failure of the integrity of tin coating in the area of maximum plastic strain with the separation of particles of the coating (b).

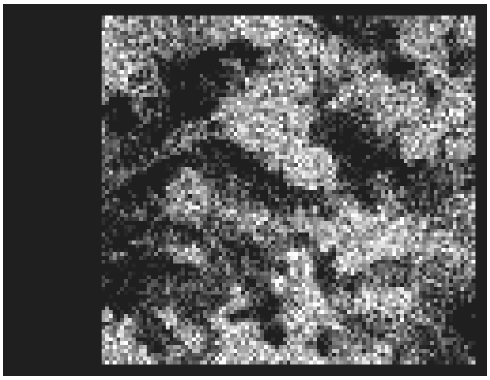


a)

DOI10.12776/ams.v21i3.590 p-ISSN 1335-1532
e-ISSN 1338-1156



b)



c)

Fig. 5 Uniaxial tension, area around the neck, fragmentation of the tin coating (a), qualitative EDX analysis (b, c)

4 Conclusions

Obtained knowledge about the failure of protective layer can be used in the plan of production of tin packages by drawing.

During the drawing process:

- the critical place with maximum deformation, where the tensile stresses predominate, is the place where the bottom and cylindrical wall of the cup meet,
- this place and the magnitude of deformation clearly depend on the radius of the cup´s rounding,
- the critical place at the two-piece cans is actually at the place where the bottom of the top and the cylindrical wall meet,
- in this place is the radius of rounding significantly smaller than at the bottom of the can that is because of the requirements for the opening of can.

Use of the knowledge should lead to the decrease of propensity of corrosive failure of tin packages, caused by the filling of can just in these critical places of package.

References

[1] R. Gburík, M. Černík, R. Legatt, P. Vranec: IOP Conference Series: Materials Science and Engineering, Vol. 82, 2015, Issue 1, DOI: 10.1088/1757-899X/82/1/012062

[2] J. Slota, E. Spišák, M. Jurčišin: Key Engineering Materials, Vol. 606, 2014, p. 23-26, DOI: 10.028/www.scientific.net/KEM.606.23

[3] H. Yu, I.W. Burgess, J.B. Davison, R.J. Plank: Journal of Constructional Steel Research, Vol. 64, 2008, No. 5, p. 515-525, DOI: 10.1016/j.jcsr.2007.10.009

[4] T. Kvačkaj, J. Bidulská: Materials Science Forum Vol. 783-786, 2014, p. 842-847, DOI: 10.4028/www.scientific.net/MSF.783-786.842

[5] M. Mihaliková, L. Ambriško, L. Pešek: Kovové materiály Vol. 49, 2011, No. 2, p. 137-141, DOI: 10.4149/km-2011-2-137

[6] T. Aerts, Th. Dimogerontakis, I. DeGraeve, J. Fransaer, H. Terryn: Surface and Coatings Technology, Vol. 201, 2007, No.16-17,p. 7310–7317, DOI: 10.1016/j.surfcoat.2007.01.044

DOI10.12776/ams.v21i3.590 p-ISSN 1335-1532
e-ISSN 1338-1156

[7] P.V. Makarov et al.: Theoretical and Applied Fracture Mechanics, Vol. 37, 2004, No. 1-3, p. 183-244, DOI: 10.1016/S0167-8442(01)00078-7
[8] T. Kvačkaj, J. Bacsó, J. Bidulská, M. Lupták, I. Pokorný, M. Kvačkaj, M. Vlado: Acta Metallurgica Slovaca, Vol. 16, 2010, No. 4, p. 268-276
[9] J. Zhang, Y.A. Jiang: International Journal of Plasticity, Vol. 21, 2005, No. 3, p. 651-670, DOI: 10.1016/j.ijplas.2004.05.001
[10] J. Zhang, Y.A. Jiang: Journal of Engineering Materials and Technology, Transactions of the ASME, Vol. 126, 2004, No. 2, p. 164-171, DOI: 10.1115/1.1647125
[11] E. Spišák, J. Majerníková: Applied Mechanics and Materials, Vol. 693, 2014, p. 340-345, DOI: 10.4028/www.scientific.net/AMM.693.340
[12] M. Kollárová, M. Džupon, A. Leško, Ľ. Parilák: Metalurgija, Vol. 46, 2007, No. 1, p. 9-14
[13] R. Sekar, C. Eagammai, S. Jayakrishnan: Journal of Applied Electrochemistry, Vol. 40, 2010, No. 1, p. 49-57, DOI: 10.1007/s10800-009-9963-6
[14] D.-H. Xia, S.-Z. Song, J.-H. Wang, H.-C. Bi, Y.-X. Jiang, Z.-W. Han: Transactions of Nonferrous Metals Society of China (English Edition), Vol. 22, 2012, No. 3, p. 717-724, DOI: 10.1016/S1003-6326(11)61236-3
[15] S.I. Wright, M.M. Nowell, D.P. Field: Microscopy and Microanalysis, Vol. 17, 2011, No. 3, p. 316-329, DOI: 10.1017/S1431927611000055
[16] N. Mora, E. Cano, J.L. Polo, J.M. Puente, J.M. Bastidas: Corrosion Science, Vol. 46, 2004, No. 3, p. 563-578, DOI: 10.1016/S0010-938X(03)00171-9
[17] X. Huang, N. Li: Journal of Alloys and Compounds, Vol. 465, 2008, No. 1-2, p. 317-323, DOI: 10.1016/j.jallcom.2007.10.093
[18] S. Blunden, T. Wallace: Food and Chemical Toxicology, Vol. 41, 2003, No. 12, p. 1651-1662, DOI: 10.1016/S0278-6915(03)00217-5
[19] M. Batzill, U. Diebold: Progress in Surface Science, Vol. 79, 2005, No. 2-4, p. 47-154, DOI: 10.1016/j.progsurf.2005.09.002
[20] D.-H. Xia, S.-Z. Song, J.-H. Wang, H.-C. Bi, Z.-W. Han: Wuli Huaxue Xuebao/ Acta Physico - Chimica Sinica, Vol. 28, 2012, No. 1, p. 121-126, DOI: 10.3866/PKU.WHXB201228121

Acknowledgement
This work was created with the financial support of the projects APVV-0682-11 and VEGA No. 1/0872/14.