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Forming-induced Gloss Reduction of Coil Coated Sheets for White Goods

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Abstract

In the household appliance industry piecework coating of body components has been successively substituted by usage of coil-coated sheets. For components with low strains or components not visible for the customer and therefore with no requirements concerning the visual impression these organic-coated materials bear a proper possibility for cost savings. But besides that, for high quality household appliances there are high visual requirements on the front panels. Already the gloss reduction of the coating layer due to higher strains restricts the application for front panels in most cases. From an economic point of view the application of coil-coated sheets even for these components is highly demanded. For an acceptable substitution the resulting paintwork properties after the forming process should be able to forecast within numerical simulations. Therefore the forming-induced gloss reduction of the respective coated material has to be determined in a proper manner.

This paper deals with analyses concerning the forming-induced and strain-state-depending gloss reduction of a coil-coated material commercially used for white goods components. The investigations include measurements of strains and gloss by using an in situ approach. For that purpose, material specimens are formed using a modified experimental setup referring to the MARCINIAK-Test (ISO 12004-2). A fundamental advantage of the in situ measurements is a minor demand of experiments together with a high resolution of the measured variables. In conclusion, based on the experimental results a conceivable forming limit criterion is defined and integrated in an exemplarily simulation model. The front panel of a front-loading washing machine is used as a practice-oriented application example. Using of the pursued approach improper gloss reductions on the formed panel can be predicted within forming simulation.

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1. Introduction and Research Objective

Since the 1960s, organic coated sheet metals are used in building industry and furniture as well as in household appliances and automotive industry. The primary strategy for the application of painted semi-finished products can be described by the term „finish first, fabricate later“ [1,2]. Therefore, piecework coating is not necessary for the component manufacturer. That leads to a reduction of the process chain or rather the vertical range of manufacturing. But the financial benefits resulting from this substitution are opposed to limitations with regard to the accessible shaping and surface quality [3].

Fundamentally, organic coated sheet metals are composite materials, consisting of a metallic substrate and an organic coating. The forming process limits are mostly determined by the organic coating, not by the sheet metal material. Various effects during the forming process influence the protective, functional and visual properties of organic coatings negatively. Typical surface defects are signs of detachment [4], cracking [5], changes in colour hue, gloss reduction and changes in roughness or waviness. On the one hand, these defects occur due to mechanical loads on the surface in manufacturing and handling [6]. On the other hand, coating properties change because of changes in shape or elongation in the forming process [1].

In the white goods sector, polyester and polyurethane coatings are common for organic coil-coated sheet metals. The structure of these coating systems is schematically shown in Fig. 1a. With regard to the elasticity these coating systems are superior to piecework coatings. The hardness and the abrasion resistance are significantly lower compared to piecework coatings or enamels [7].

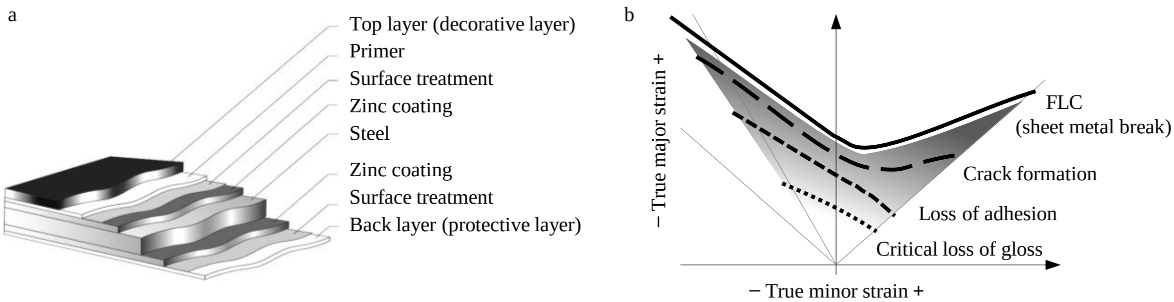

Fig. 1. (a) Structure of organic coated steel sheets [8]; (b) Fictitious forming limit diagram with coating-FLCs based on specific criteria.

Fig. 1b shows a fictitious example of the FLC (forming limit curve) of a metallic substrate and limit curves of different evaluation criteria regarding the organic coating. Besides yes/no criteria describing the first appearance of a defect such as cracking or delamination, there are quantitative limit values for evaluation criteria, which are changing while increasing the deformation. In the FLD (forming limit diagram), the deformation due to reaching the limit condition corresponds to a coating related forming limit curve (coating-FLC). In principle, such a coating-FLC can be compared to the FLC of a sheet metal. But the relevant evaluation criterion for a coating-FLC depends on the coating and the specific application.

The analyses described in this paper involve the application of a developed in-situ test method to determine the forming induced gloss reduction of an organic-coated sheet metal in the white good sector. The test concept and the results are explained as well. Moreover, the application of the gained results in the form of a coating-FLC will be shown. The defined coating-FLC is used to identify critical forming conditions or component areas already within the part and process design by simulating the forming process. As a practice-oriented application, the drawn part of the front panel of a washing machine is considered.

1.1. Object of Study

The considered test material is a deep drawing sheet metal DX54D+Z100 with a thickness of 0.88 mm and a PUR-coating. As typical for household appliances, the coating has a structured surface, which looks similar to piecework painted or enameled surface. Therefore, the two-layer coating consists of a structured primer and a PUR topcoat. It has a high-gloss surface with the color hue “Lotos White“. The total layer thickness is between 25 and 30 μm. The material is already used in household appliance industry for sheet metal components with low deformation such as the side walls of washing machines and tumble dryers. Apart from the color, the surface gloss is a quantitative measurable quality criterion and subjects to high demands of the end costumers, specifically in the viewable area. The gloss value of this material at initial state G_0 is about 68 GU (gloss units) at the normed measurement angle of 20° and 91 GU at the normed measurement angle of 20° (see [9]). For the conduced gloss measurement a gloss meter type Zehntner ZGM 1120.26 was used.

2. Experimental Procedures and Results

In the following, an in-situ method to characterize the forming induced gloss reduction of organic-coated sheet metals is described. The measurement data of this method can be used to define a coating-FLC. The main difference to established ex-situ methods is the realization of a continuous measurement of the gloss value and strain values during the forming process. The measurement of both variables simultaneously is the basic prerequisite for a suitable test concept. Ex-situ test concepts, existing in literature [3, 4, 10], use the NAKAJIMA-test setup. Differently from those, only the MARCINIAK-test setup [11] allows the integration of an in-situ gloss measurement.

2.1. Integration of a Gloss Meter into the MARCINIAK-Test Set-up

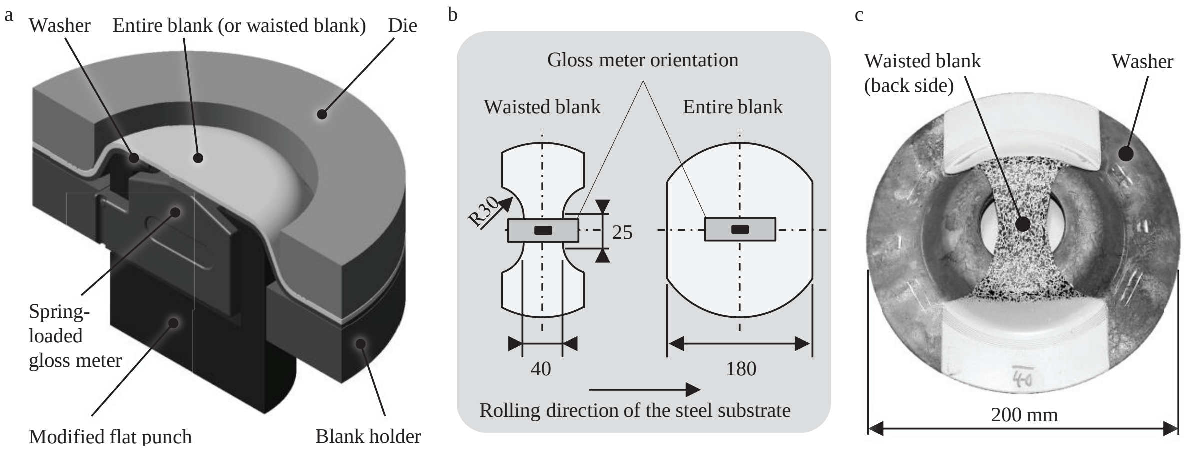

Fig. 2. (a) Half-sectional view of the modified set-up; (b) Considered specimen shapes; (c) Specimen and washer after test procedure.

Fig. 2a shows a simplified model of the modified test setup according to DIN EN ISO 12004-2 [12]. The flat punch with a diameter of 100 mm has a complex designed pocket for the gloss meter. In the flat punch, the gloss meter is axially directed and spring mounted, to ensure a continuous contact to the coated sample during the forming process. The gloss meter passes through the bore of the washer with a bore diameter of 38 mm.

The test series focus on the sample geometry shown in Fig. 2b. Based on previous ex-situ test series [13], it is shown that coating-FLCs regarding the loss of gloss can be described in the FLD by straight lines. Consequently, only two sample geometries are necessary for the analyses. This is a considerable difference to FLCs regarding the cracking appearance in sheet metals. For those, a minimum of five sample geometries is necessary according to DIN EN ISO 12004-2 [12]. The chosen sample geometries for the coating-FLC represent the area of the uniaxial tension (waisted blank) and the equivalent biaxial tension (entire blank).

A characteristic feature of the chosen test concept is that the sample surface with the organic coating is directed to the flat punch and the gloss meter, respectively. On the backside of the sample, a stochastic measurement pattern is applied before the test for the strain analysis system GOM ARAMIS (see Fig. 2c) [14]. Because of the flat area in the middle of the sample, strains at both sides of the sheet are identical. Thus, a linking of the measurement data of the opposing sides is feasible.

2.2. Results and Discussion

For both sample geometries, Fig. 3a shows the measurement results regarding the relative loss of gloss LG as a function of the equivalent total strain $\varepsilon_{\mathrm{eq}}$ according to VON MISES. The relative loss of gloss LG is calculated on the basis of the ratio of the forming induced loss of gloss ΔG_{i} and the gloss value at initial state [4]. The loss of gloss ΔG_{i} is equal to the difference of the gloss value at initial state G_0 and actual gloss value of the deformed specimen G_{i}.

$$LG_{\mathrm{i}} = 100 \cdot \frac{\Delta G_{\mathrm{i}}}{G_0}\ [\%] = 100 \cdot \frac{G_0 - G_{\mathrm{i}}}{G_0}\ [\%] \quad (1)$$

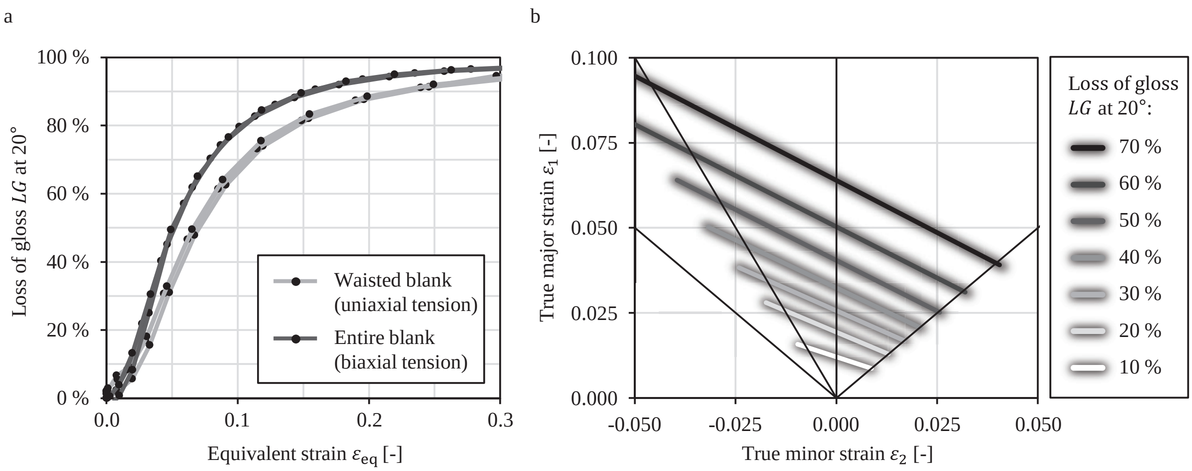

Fig. 3. (a) Loss of gloss related to equivalent strain measured through in situ test procedures (n=3); (b) Forming-related gloss-reduction diagram.

Due to the high gloss at initial state, according to DIN EN ISO 2813 [9] the measuring angle of 20° is relevant for the evaluation of this coating. The results show the progression of the relative loss of gloss caused by increasing strain. The marked measuring points are the result of continuous gloss measurements during the forming process with an interval of 1.5 seconds. The biaxial tension basically leads to a higher gloss reduction than the uniaxial tension. In this case, a gloss reduction up to 60 % at a measurement angle of 20° can be considered. Above that, the saturation area of this measuring geometry will be reached, explaining the presented curve progression. Comparative analysis above this limit value is allowed though.

To represent the results in relation to define a coating-FLC, the relative loss of gloss is mapped in a FLD in Fig. 3b. This FGRD (forming-related gloss-reduction diagram) shows the relative loss of gloss in 10 %-steps. The straight lines are interpolated from the measuring data. A maximum limit of gloss reduction can be chosen to the specific application. On the example of this coating, in the viewable area for the costumer a loss of gloss of 50 % is defined as the limit by the component manufacturer, who processes the material in serial production. Consequently, the third curve from above represents the coating-FLC, which is chosen for the following application example.

2.3. Application

In the completing section of these investigations, the focus is on the application of the defined coating-FLC. Test samples produced in the laboratory showed successfully that coating-FLCs are useful to predict quality-critical deformations within forming simulations. Beyond that, this paper presents a practice-oriented application example in form of a sheet metal forming component in the field of white goods. Therefore, the coating-FLC will be integrated into the material chart of the simulation model.

Within the scope of this paper, the drawn part of a front-loading washing machine can be considered (see Fig. 4a/b). In serial production, for this part unpainted sheet metal is still used and piecework coated after the forming processes. But in this experiment, the PUR-coated sheet metal material analyzed before is investigated. After the drawing operation no following process steps are considered. The drawn part geometrically consists of a deep drawn outer rectangle cup and an indentation for the front hatch. In the lower indentation area, formed flat areas exist with linear strain paths and a sufficient accessibility for the gloss meter. Therefore, two inspection points with the same strain values are chosen (see Fig. 4c).

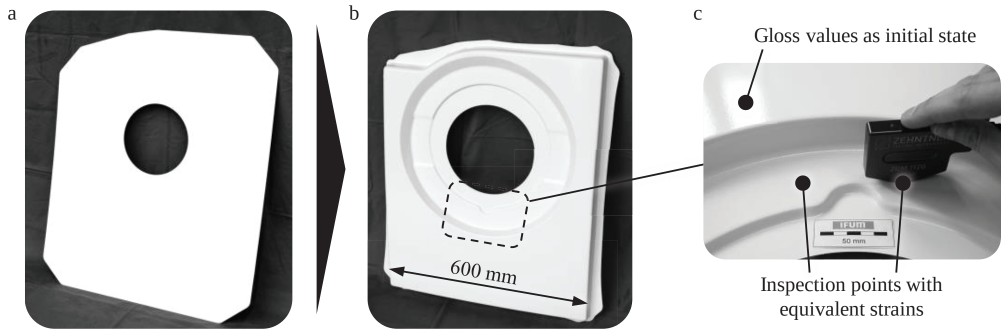

Fig. 4. (a) Shaped blank; (b) Drawn part for front panel; (c) Inspection points for gloss measurements at the lower indentation area.

Fig. 5a shows the simulation result of the drawn part, regarding to the outer side of the sheet metal, which also features the front side coating on the real drawn part. Strains above the coating-FLC, leading to a gloss reduction of more than 50 %, are illustrated with a dark colour. The coating-FLC is exceeded significantly at the inspection points. In Fig. 5b the strain path is sketched. A gloss reduction of more than 70 % can be read in the FGRD. This matches with the experimentally investigated loss of gloss of 71.7 %, averaged on three drawn parts. Of course, the protective foil, which protects the coating from abrasion in the forming tool [5], has been removed before the gloss measurements.

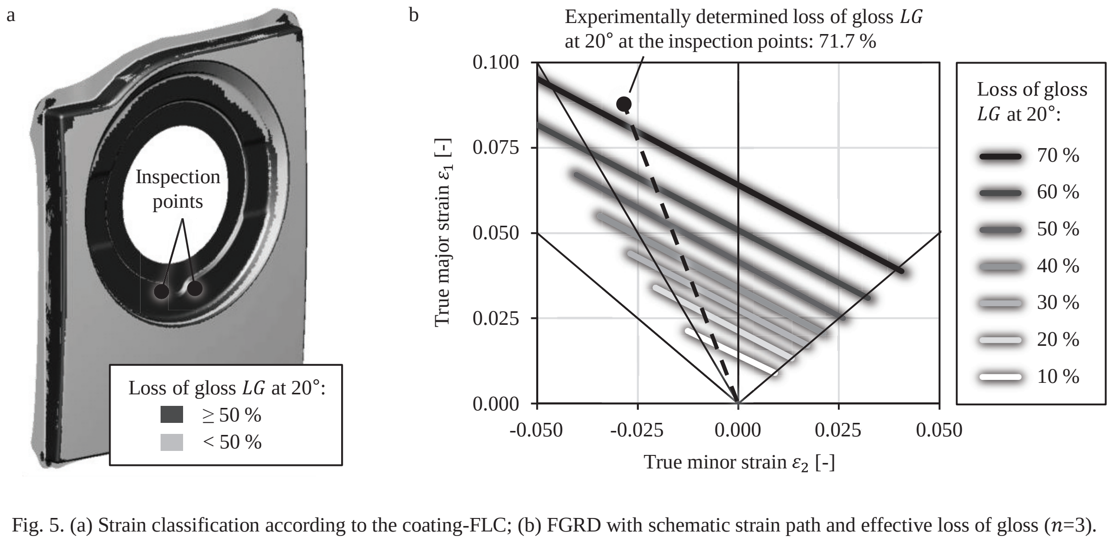

Fig. 5. (a) Strain classification according to the coating-FLC; (b) FGRD with schematic strain path and effective loss of gloss (n=3).

3. Summary

This paper focused on the development of an in-situ method to determine the forming induced loss of gloss of organic coil-coated sheets. The test is based on the test setup according to MARCINIAK, which is normally used to determine FLCs of sheet metals. The test setup has been modified to measure the gloss value and the strains from different shaped samples during the forming process simultaneously. The data basis to define a coating FLC referred to a quality critical loss of gloss can be determined with a small test effort compared to ex-situ methods. As the criterion for the coating-FLC, in this paper a loss of gloss of 50 % has been chosen. The drawn part of a front-loading washing machine has been considered as an application example, both experimentally and within forming simulation. By means of the coating-FLC component areas can be easily identified, which feature an inadmissible high loss of gloss. The comparison of the experimental and simulative results shows a high congruence. Consequently, the chosen test method as well as the approach within forming simulation using a coating-FLC are useful to predict the loss of gloss already in the field of part and process design. This paper focused exemplarily on a coil-coated material for household appliance industry. But the presented approach can be adopted on various products formed out of coil-coated sheet metal.

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References

[1] Jandel, A.-S., Meuthen, B., Coil Coating, third ed., Springer Fachmedien, Wiesbaden, 2013.
[2] ECCA-Gruppe Deutschland e.V., Finish first, fabricate later, 2016, available on: http://www.ecca.de/coil_coating/finish_first_fabricate_later/.
[3] Goldschmidt, A., Streitberger, H.-J., BASF Handbuch Lackiertechnik. second ed., Verlag Vincentz Network, Hanover, 2014.
[4] Behrens, B.-A., Gaebel, C. M., Formability of an anti-fingerprint clear coating on satin stainless steel sheet metal, in: Prod. Eng. Res. Devel. April 2013, Volume 7, Issue 2, pp. 275 - 281.
[5] Pham, H.-D., Trompeter, M., Tekkaya, A. E,: Erratum to: On the reduction of gloss property of organic coated sheet metals after forming, in: Prod. Eng. Res. Devel. October 2010, Volume 4, Issue 5, pp. 483 – 489.
[6] Behrens, B.-A., Hübner, S., Gnaß, S., Gaebel, C. M., Bewertung von Zieh- und Schutzfolien für die Umformung von organisch bandbeschichteten Feinblechen. In: Whitepaper by umformtechnik.net, Meisenbach Verlag, Bamberg, 2016.
[7] Stahl-Informations-Zentrum, Charakteristische Merkmale 093: Organisch bandbeschichtete Flacherzeugnisse aus Stahl, Düsseldorf, 2012.
[8] Arcelor Flat Carbon Steel Europe, User Manual: Organic Coated Steel, Luxemburg, 2004.
[9] Norm DIN EN ISO 2813, Paints and varnishes - Determination of gloss value at 20°, 60° and 85°, Beuth Verlag, Berlin, 2015.
[10] Son, Y. et al., Experimental evaluation of coating delamination in vinyl-coated metal forming, in: Journal of Mechanical Science and Technology, No. 26(10), pp. 3223-3230, 2012.
[11] Behrens, B.-A., Bouguecha, A., Krimm, R., Hübner, S., Peshekhodov, I., Gaebel, C. M., Altan, L., Influence of the martensitic transformation due to shear cutting on the edge cracking sensitivity of metastable austenitic stainless steels, in: 10th Conference Advanced Metal Materials and Technologies, June 25th-29th 2013 in St. Petersburg, pp. 260-265, 2013.
[12] Norm DIN EN ISO 12004-2, Metallic materials – Sheet and strip – Determination of forming-limit-curves – Part 2: Determination of forming-limit-curves in the laboratory, Beuth Verlag, Berlin, 2008.
[13] Zarembik, T., Untersuchungen von dehnungsinduzierten Eigenschaftsänderungen bei organischen Bandbeschichtungen für die Hausgeräteindustrie, Leibniz Universität Hannover, student research paper, 2015.
[14] Behrens, B.-A., Voges-Schwieger, K., Bouguecha, A., Mielke, J., Vucetic M., Material Characterization for Sheet-Bulk Metal Forming, in: Key Engineering Materials Vols. 504-506, pp. 1029-1034, Trans Tech Publications, 2012.