PROPERTIES ANALYSIS OF COATINGS WITH LAYER ZINC/MAGNESIUM AT SHEETS FOR CAR-BODY PRODUCTION

Ing. Michaela Kolnerová, Ph.D.
Technická univerzita v Liberci
Fakulta strojní
Česká republika, Liberec 461 17, Studentská 2
e-mail: michaela.kolnerova@tul.cz

doc. Ing. Pavel Solfronk, Ph.D.
Ing. Jiří Sobotka, Ph.D.
Ing. Pavel Doubek, Ph.D.
Ing. Lukáš Zuzánek
Technická univerzita v Liberci
Fakulta strojní
Česká republika, Liberec 461 17, Studentská 2

Abstract

This paper deals with the comparison of sheets utility properties with zinc coatings that is commonly using for car-body stampings production (Z100) and with newly developed coating (ZM). Analysis of utility properties is carried out by tribological testing (strip drawing test). Moreover there is evaluation of bonded joints strength for both coatings cause bonding represents subsequent operation of jointing and joint quality is one of the crucial criterions for car-body production.

Key words: coatings, zinc, magnesium, tribology, adhesive

INTRODUCTION

Sheets as partial components of car-body are produced mainly by deep-drawing technology. Deep-drawing technology of non-regular shape parts (so-called car-body stampings) represents one of the most complicated operation. On the sheet as construction material are set still new requirements. Standard low-carbon steel sheets for car-body design are these days using very rarely. Such material type was mostly replaced by coated steel sheets. These sheets have to fulfill requirements about good process-ability and simultaneously coating layer has to provide effective protection against corrosion [1, 2].

Importance of materials whose surface is modified is still increasing and there is put quite large attention to these materials. In automotive industry are mostly utilized sheets with coating based on the zinc layer. Zinc is suitable mainly due to its relatively low cost and very good protection against corrosion. For car-body stampings are very often used sheets both hot dip galvanized and electro-galvanized with protection layer on one or both sides. As a problem arising from using coated sheets there is decline of coated layers quality at stamping itself when there is adhesion between sheet coating and tool. Quite often there is galling or scratching of zinc layer at zinc coated sheets.

That is why sheet producers are still trying to find out new methods hot to improve coatings, types, properties and methods of their preparation. Besides conventional coating on the zinc basis are these days tested coating based on compound of zinc and magnesium. Great attention in also put to determination the properties loss of new coatings and their waste during own sheet drawing process. To obtain perfect information about real tribological system of coatings is quite difficult and that is why there are carry out laboratory tests.

1 SHEETS WITH PROTECTIVE LAYER ZM

Metal coatings based on the zinc and magnesium (ZM) represent another level in development of hot dip galvanized coatings with anti-corrosion properties. ZM coatings are produced by alloying of zinc by magnesium (Mg) and aluminium (Al). Thus there is created protective layer with many advantages in comparison to conventionally used zinc coatings. In Fig. 1 is shown characteristic of Z100 coating, zinc coating with amount 100 g/m² produced by hot dip galvanizing method (HDG). In Fig. 2 is shown characteristic of ZM coating (coating composition 2.0% Mg, 2.0% Al and 96.0% Zn).
Mechanical properties of sheets in direction $90^\circ$ (toward rolling direction) are summarized in Tab. 1 [3]. ZM $3.0\%$ Mg, $3.7\%$ Al, $93.3\%$ Zn).

Tab. 1 Mechanical properties of sheets in direction $90^\circ$ (toward rolling direction)

<table>
<thead>
<tr>
<th>$90^\circ$</th>
<th>Mechanical properties of ZM and Z100</th>
<th>$R_{p0.2}$</th>
<th>$R_m$</th>
<th>$\Delta_k\text{mm}$</th>
<th>$r$</th>
<th>$n$</th>
<th>$t$</th>
</tr>
</thead>
<tbody>
<tr>
<td>ZM</td>
<td></td>
<td>225</td>
<td>333</td>
<td>39.5</td>
<td>2.33</td>
<td>0.199</td>
<td>0.70</td>
</tr>
<tr>
<td>Z100</td>
<td></td>
<td>143</td>
<td>286</td>
<td>44.1</td>
<td>2.51</td>
<td>0.230</td>
<td>0.73</td>
</tr>
</tbody>
</table>

ZM coating due to their protection against corrosion are superior to coatings using these days, thickness of metal layer in comparison to common zinc coatings can be markedly lower. In Fig. 3 and 4 is comparison of both layers from corrosion-proof tests (samples are after 90 cycles in salt mist). It is evident that ZM coating ($3.0\%$ Mg, $3.7\%$ Al, $93.3\%$ Zn) reveals better protection against corrosion.

Beside better corrosion-proof resistance ZM coatings have also better technological properties and their surface is harder and with higher abrasion and wear resistance. These coating have better deep-drawing properties and during painting reveal good cohesion of painted layer thus ensuring quality appearance of future part.

To determinate technological utility properties of protective coatings was chosen tribological test (strip drawing test).

2 TRIBO-PROCESSES

Description of tribological conditions in system device – tool – material is essential part of drawing process these days. Research in this field has easily found its utilization also for numerical simulations of drawing process which are commonly used during stamping proposal.

At Technical University of Liberec and in with cooperation with ŠKODA AUTO a.s. there was developed testing device SOKOL 400 for evaluation tribological properties. Its design enables to carry out tests under conditions which are close to conditions during real car-body stamping.

2.1 Experimental measurement of coatings tribological properties

Principle of device and test description are in detail described e.g. in [4] and are also published in many technical papers which deal about tribological topic that is researching at Technical University of Liberec [5,6,7].

For experimental measurement was used variant 1A [4] – simulation of drawing conditions over the drawing edge with drawing radius $R = 3$ mm (Fig. 5), as a tool material was used non-hardened cast iron GGG 70L, tool temperature was $60\pm2\text{°C}$ according to real stamping conditions.

As a tested material was chosen steel sheet Z100 (Hot Dip Galvanized – HDG) and sheet with the new surface ZM.

2.2 Condition of experiment [3]

- Sliding velocity : $v = 1\text{mms}^{-1}$
- Lubricant: AC PL 3802-39S (1.5g/m²)
- Contact pressure : $p = 4;6;8\text{MPa}$
- Temperature tool: $T = 60\pm2\text{°C}$
- Contact area tool: $S = 3120\text{mm}^2$
- Material tool: GGG70L (unhardened)
- Radius tool $R = 3$ mm
- Substrate: Steel sheet (Z100, ZM)
- ZM: $3.0\%$ Mg, $3.7\%$ Al, $93.3\%$ Zn

2.3 Results of tribotest

As a result from measurement there is diagram of dependence force – displacement which serves as basis for evaluation coatings tribological properties. In the fig. 6 and 7 are shown courses from individual measurements.
As a primary evaluation criterion of tested coatings suitability was selected the size of drawing force $F_A$ at drawing strip over the drawing edge which clearly provides the differences between coatings quality and their drawing suitability. Differences between drawing forces are graphically shown in Fig. 8. For ZM coating has Drawing Force $F_A$ lower by 36.25% for contact pressure 4MPa. For 6MPa contact pressure has $F_A$ lower by 42.4% a than the coating Z100.

Within the evaluation of bonded joints strength of sheets with coating ZM it is necessary to obtain correct data, to verify jointing methods and compare them with coating Z100 which is normally used during car-body production.

**3.1 Evaluation of bonded joints strength**

Bonded joints are characteristic for their good shear strength, tensile strength is already a little bit lower and the worst properties are revealed under peel loading (see Fig. 9).

Within the evaluation of bonded joints there was carried out test to determinate bonded joints peel strength according to ISO 11339 [9]. Standardized sample for test (see Fig. 10), test results are plotted in the graph (Fig. 11).

**3.2 Conditions of bonding [3]**

- Lubricant: AC PL 3802-39S (3g/m²)
- Adhesive: (1) Semi crash-resistant
  (2) Elastic rubber
  (3) High-strength rubber
- Setting: Temperature 180°C – Time 20 min
- Coating ZM: 3.0% Mg, 3.7% Al , 93.3% Zn

**3 ADHESIVE BONDING**

Utilization of new coatings means also necessity to test utilization properties of individual bonded parts - mainly under the peel loading in dependence on adhesive and lubricant uses in technological process of car-body stamping. Sheet stamping as partial part of car-body are produced by drawing (deep-drawing) process and utilization coatings reveals some complications which are connected with technologies for their processing and subsequent assembly.
3.3 Evaluation of bonded joint fracture type

As another criterion to evaluate bonded joint quality there is evaluation of bonded joint fracture type according to ČSN ISO 10365 [9]. Basic fracture types are shown in Fig. 9 (a) CF – cohesion fracture, (b) SCF – special cohesion fracture, (c) AF – adhesion fracture.

In fig. 10 and 11 are shown results of joints fracture types [%] of both coatings for semi crash-resistant adhesive (1)

In fig. 12 and 13 show fracture type results [%] of both coatings for elastic rubber adhesive (2)

In fig. 14 Coating Z100, CF 100 [3]

CONCLUSION

Properties analysis of sheets with coatings for car-body stampings was in tribo-processes carried out by experimental tribological tests which were focused on the determination of new hot dip galvanized zinc coating type (ZM) suitability with new composition beside basic zinc element and alloys of magnesium and aluminium (specific composition ZM 3.0% Mg, 3.7% Al, 93.3% Zn).

These sheets should replace conventionally used zinc-coated sheets for production car-body panels. As a requirement for their application in series production there is minimization of negative effects at drawing – to lower friction and eliminate galling.

With regard to reliability of tribological processes was measurement carried out at sliding speed 1 mm/sec when the galling effect has the strongest influence and qualitative difference between individual coatings becomes evident. From Fig. 6 and 7 where are presented graphs of individual forces courses is evident that coating ZM reveals better tribological properties at drawing because at adjustment contact pressure 8 MPa there was not possible to draw strip with coating Z100. This sample revealed galling up to its fracture. On the base of measured values it is possible to state that in light of tribological properties coating ZM satisfied for given testing parameters combination.

Knowledge obtained from these experiments is just partial component for evaluation tribological properties for system: tool – material – lubricant – technological conditions because as a
final criterion for coating suitability it is not only value of force necessary to draw material but it is important to also take into account used lubricant and tool material and another technological conditions (see chapter 2.2.).

At coatings ZM (specific composition 3.0% Mg, 3.7% Al, 93.3% Zn) and Z100 were also evaluated utility properties in light of bonded joints strength. Sheet samples were tested at peel test according to ISO 11339. Peel is the worst loading type for adhesion at bonding.

Experiments proved that peel strength is lower for ZM coating than for coating Z100 (see Fig. 11). Adhesive 1 has peel strength for ZM coating lower by 33.3%, adhesive 2 lower by 32.3% and adhesive 3 lower by 8.45%. It cannot be stated that coating ZM reveals worse results in this case because these results are influenced by other factors like are e.g. mechanical properties of tested substrates (see Tab. 1) and it depends also on the fracture type of joint.

By reason of complex bonded joint quality appreciation there serves beside evaluation of strength properties also visual evaluation of bonded joint fracture type according to ČSN ISO 10365. There were evaluated individual fracture types of both coatings after sample destruction by tensile loading. In light of used adhesive types it’s possible to state that at using adhesives 1 and 2 there were obtained acceptable fracture types CF or SCF for both coating types (see Fig. 13 till 16). Coatings ZM has higher percentage of fracture type CF which is more favorable fracture type than SCF. In the case of adhesive 3 there was obtained for coating ZM also adhesive fracture type – 5% AF (see Fig. 18). In light of bonded joints quality evaluation is adhesive fracture type non-acceptable. On the other hand there were the lowest deviations in peel strength between coatings (only 8.45%) for adhesive 3.

Presented results from experimental laboratory tests (Fig. 11 till 18) proved some facts about utilization of new coating type ZM (specific composition 3.0% Mg, 3.7% Al, 93.3% Zn). Not always were these results favorable for this new coating type than for the conventional coatings. However there is necessary to take into account that bonded joint quality into a great extent depends on many factors like is e.g. amount and type of used lubricant, type of used substrate and its surface morphology or surface treatment. Such huge amount of variable parameters makes problems about testing bonded joint quality quite difficult and requires further deepening of knowledge about individual parameters influence.

Advantage of newly developed coating ZM utility properties is increasing corrosion resistivity (see Fig. 3). Such increasing resistance against corrosion means long service life of car.

For application of new coating types into series production in automotive industry will be necessary to define coating specific properties with regard to requirements for good formability but simultaneously also for bonded joints quality.

It is necessary to carry out more technological and tribological tests to be able to state that coating ZM has a potential to compete with conventional zinc coatings.

References


Acknowledgement

This paper was supported by project Student Grant Contest from the TUL/SGS 28005/ with the cooperation of SKODA AUTO a.s. Mladá Boleslav, Czech Republic