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Influence of Draw-Beads Geometry on the Surface Quality of Zn-Mg Coating

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In terms of surface protection of outer car body parts, zinc coatings are currently highly used in automotive industry. Concretely, hot dip galvanized (HDG) sheets are used in most cases. However, other possible alternatives such as zinc-magnesium coatings (Zn-Mg), which are usually referred to as ZM coatings, are also more frequently applied. Thanks to magnesium, the corrosion resistance is significantly increased, which also positively influences the coating thickness. On the other hand, the presence of magnesium makes this coating harder and brittle, which significantly limits its use to produce complex car-body stampings. To prevent the stamped material being drawn into certain parts of the drawing die, special types of draw-beads (so-called edge beads) are used. The effect of draw-beads geometry on the level of damage of ZM coating using experimental tests is evaluated in this article. For comparison, the same experiments were also done for HDG zinc coated specimens. Then the comparison of both methods using TESCAN MIRA3 scanning electron microscope was used and the level of damage of both tested coatings was assessed.

Keywords: Zn-Mg coating, Draw-beads, Car body stampings, Electron microscope, Surface quality

1 Introduction

The development and production of an automobile is a very complex process that is influenced by many factors. Generally, in the automotive or aerospace industry, there are requirements for high functionality, safety, external appearance, resistance to external influences and many others [1, 2]. One of the main and most important part of the vehicle is car body, which is also subjected to several requirements, which must be matched by the materials and the used production technology. In the case of structural body parts, high strength, and the ability to absorb energy during the impact are important [3]. In the case of outer surface car-body parts, very good formability, and the ability to create complex shapes are important. Therefore, deep-drawing steels are used for these applications and can meet these requirements. However, the problem is the low corrosion resistance of these materials. Since the car is in direct contact with the external corrosive environment, adequate protection must be provided for the external steel parts. Corrosive environments such as high humidity and the presence of salts, accelerate the corrosion attack on steel parts and have a significant effect on their appearance and mechanical properties [4, 5].

One of the most widely used methods of protection car body sheets is zinc coating. This is a very important process as it can extend the life of the car-body components and reduce the cost of producing new steel parts with a positive impact on greenhouse gas production [6]. Thanks to the coating that adheres to the surface, a barrier is created against the external corrosive environment. Different technologies are used to apply the coating, most commonly hot-dip galvanizing (HDG) and electro galvanizing (EG). Body parts made of deep-drawn steels are most often coated by HDG process [7, 8]. The use of this process ensures corresponding adhesion of the coating, very good formability of coated sheets and it is simple process with relatively low costs [7, 9].

Recently, especially with the ongoing transition to other types of car powertrains, such as hybrid or electric, the requirements for car bodies have been expanding [10]. In particular, the requirement to reduce the weight of parts is becoming increasingly important. Therefore, the aim is to develop new coatings with better properties, especially corrosion resistance and durability. This makes it possible to achieve a lower coating thickness and thus save both material and the resulting weight of the part, to which the weight of the coating also contributes.

Currently, both binary and ternary zinc alloys are being used for coatings. Among the binary alloys, Zn-Al, Zn - Mg and Zn-Mn are the most common [11, 12]. Of the ternary alloys, it is possible to mention e.g., Zn-Mg-Al [13]. The use of magnesium is particularly advantageous as it significantly increases corrosion resistance. However, the problem remains the resulting brittleness of the coating, which increases with increasing magnesium content. This negatively affects the resulting surface quality because the coating is than susceptible to cracking [14]. For this reason, the magnesium content needs to be properly assessed. Another important parameter influencing the final surface quality is the setting of the forming machines during the forming process [15]. It especially concerns the correct setting of the forming parameters and the geometry and functional parts of the forming tools [16]. For these reasons, the article investigates the influence of the draw-beads geometry on the final surface quality of Zn-Mg coated sheets. Moreover, as a reference conditions, there was also tested the commonly used hot dip galvanized zinc coated sheet.

2 Basic mechanical properties of tested material and overview of performed experiments

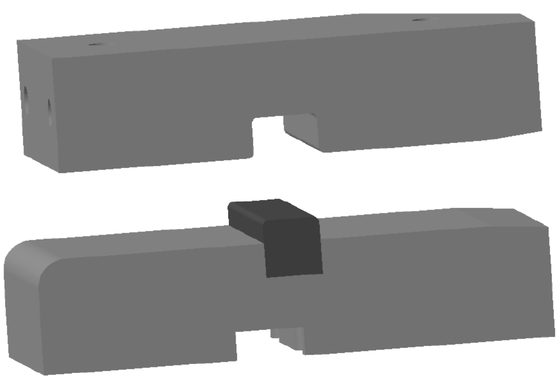
Deep-drawing sheet CR 180BH that is commonly used in the automotive industry to produce outer car-body panels, was used as a basic material for testing. Considering the surface coatings, there was tested both quite newly developed zinc-magnesium coating (in the experimental part marked as ZM) and the conventional type of coating, which represented the hot dip galvanized zinc coated sheet – marked as HDG.

First, basic mechanical properties of the tested materials were measured at room temperature. There were measured two basic strength properties (proof yield strength $R_{p0.2}$ and ultimate strength R_m) and two formability properties (uniform ductility A_g and total ductility A_{80mm}). Results, which are typical of deep-drawing materials, are summarized in Tab. 1. Static tensile test was carried out acc. to standard EN ISO 6892-1 [17].

Tab. *1 Basic mechanical properties of the tested deep-drawing material CR 180BH*

Zinc coated deep-drawing material	**Basic mechanical properties**			
	Strength properties		Formability properties	
	$R_{p0.2}$ [MPa]	R_m [MPa]	A_g [%]	A_{80mm} [%]
ZM	207,2	320,6	20,92	36,63
HDG	217,3	319,4	20,14	35,21

The own influence of draw beads geometry on the surface quality of tested surface coatings was determined by performing the tribological strip drawing test. During this test is sheet sample drawn between the testing jaws (see Fig. 1), whose design makes possible to easily change the height h [mm]of edge-beads. Friction coefficient or e.g. different types of tribological forces are commonly determined from this testing. Nevertheless, just surface quality was monitored in this research. The common washing lubricant (Fuchs 39 LV) was used during the testing.



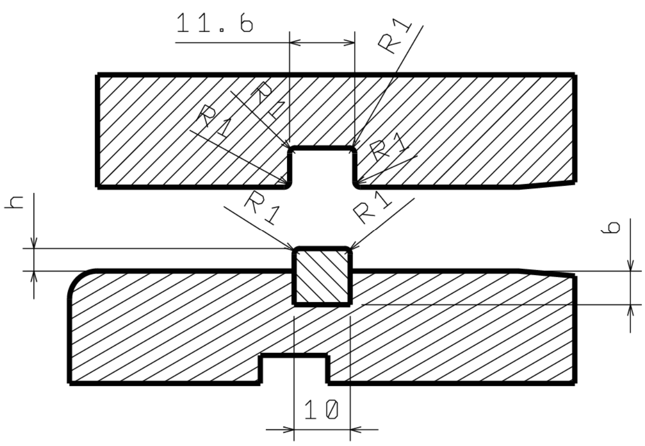


Fig. 1 *Schematic representation (left) and technical drawing (right) of the testing jaws*

In Tab. 2 are summarized all input parameters (including the variable ones that are displayed in bold), which was used during the experimental. Generally, there were used four different heights of edge beads and two testing methods from the tribological point of view. Influence of the edge beads geometry on the surface quality of two tested coatings (ZM and HDG) was subsequently determined from the average width of major cracks w [μm].

Tab. 2 *Overview of the performed experiments and major measured quantity*

Height of edge bead h [mm]	Basic parameters of tribological testing		Measured quantity
1 mm	Material of testing jaws	GGG 70L	**Average width of major cracks w [μm]**
2 mm	Sliding speed	1 mm·sec^{-1}	
3 mm	Temperature	40 °C	
4 mm	**Testing method**	**“fixed” and “free”**	

3 Tribological testing

Own tribological testing jaws, which enables to use different geometry (in this case just height of edge beads), together with used set of edge beads, are shown in Fig. 2.

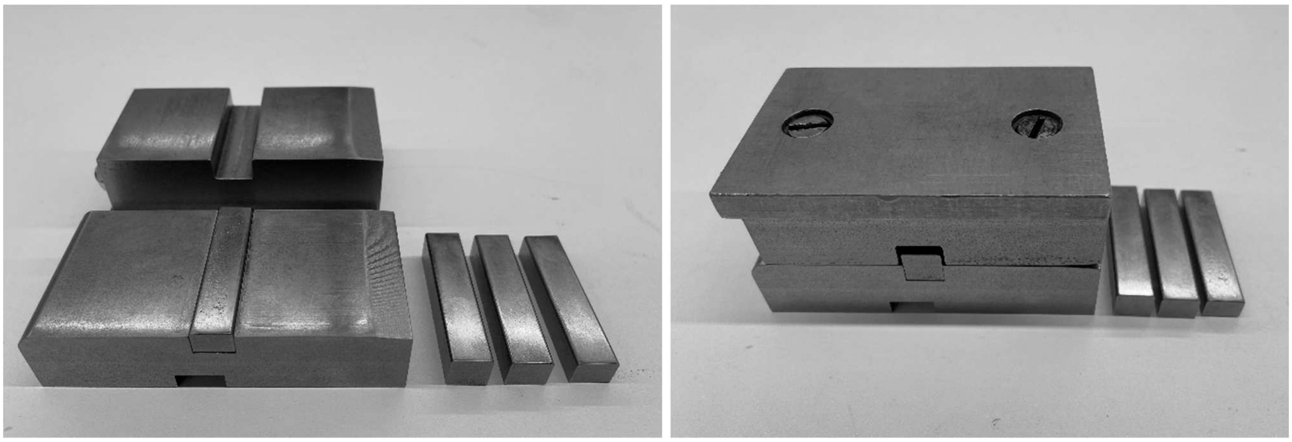


Fig. 2 *Testing jaws with the used set of edge beads – open (left) and closed (right) without testing sheet*

Tribological testing was subsequently performed on the device SOKOL 400, whose central part is shown in Fig. 3. Testing jaws were placed in the testing tool (no. 3). Regarding the testing procedure, there were two basic methods – so-called “fixed” and “free” method. During fixed method was at first the testing strip clamped by the hydraulic grips and only then was applied contact pressure (3 MPa) between testing jaws. In the second case (free method), it was vice versa. The reason was to determine the effect of the (non)possibility of strip displacement.

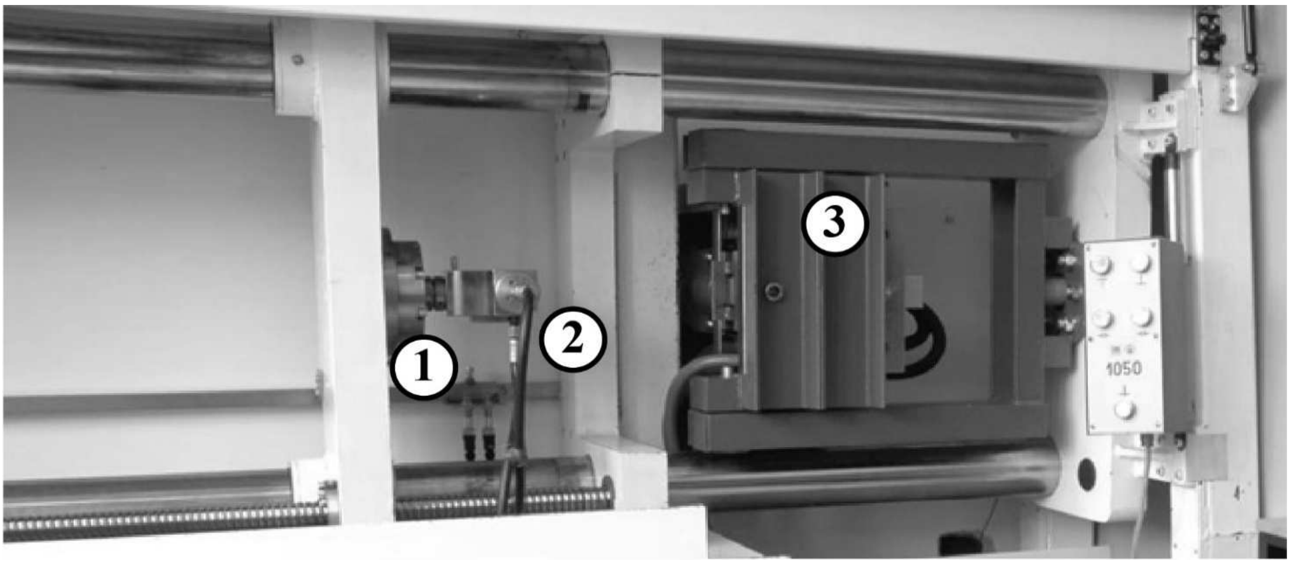


Fig. 3 *Device SOKOL 400 (1 – load cell, 2 – hydraulic side action grips, 3 – testing tool)*

In Fig. 4 are shown testing strips after the tribological testing at using different heights of edge beads. In addition to that, areas for the subsequent analysis of surface damage are highlighted.

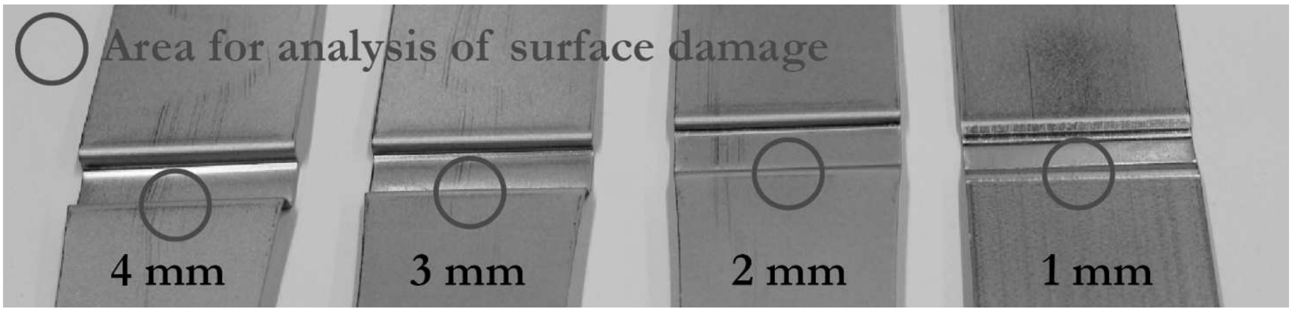


Fig. 4 *Testing strips after tribological testing for all used heights of edge beads (1, 2, 3 and 4 mm)*

4 Analysis of the surface damage

Scanning electron microscope TESCAN MIRA 3 was used to analyse prepared samples after the tribological testing. Generally, there were evaluated 4 images from every tested condition (type of coating – ZM and HDG; height of edge bead – 1, 2, 3 and 4 mm and tribological testing method – fixed and free method). The width of major (i.e. the biggest ones) cracks was always determined form the scanned images. Typical images of surface damage for all tested conditions are shown in the fig. 6 - 13. Moreover, there are also shown widths (marked as D1 and D2) of the major cracks for relevant tested condition. Arithmetic means of widths are given in Tab. 3.

Tab. 3 *Typical width of cracks in dependence on type of coating, depth of edge bead and method of tribological testing*

Height of edge bead h [mm]	Average width of major cracks w [µm]			
	ZM		HDG	
	ZM – fixed	ZM - free	HDG - fixed	HDG - free
1 mm	**5,58**	**7,74**	**0,87**	**1,12**
2 mm	**6,19**	**6,89**	**1,57**	**0,84**
3 mm	**8,28**	**8,11**	**1,52**	**1,27**
4 mm	**18,23**	**13,46**	**0,85**	**1,33**

Graphically and digestedly are these results given in Fig. 5. In dependence on the height of edge bead are there shown both tested types of coating (ZM and HDG) and methods of tribological testing – these are always shown in the same colour as coating type, but at different transparency. At first sight there is evident big difference between used surface coatings. While Zn-Mg coating reveals extensive cracking, conventional zinc coated sheets (HDG) were able to undergo tribological testing almost without any surface damage. In addition to that, the higher height of edge bead caused more extensive surface damage of ZM coating.

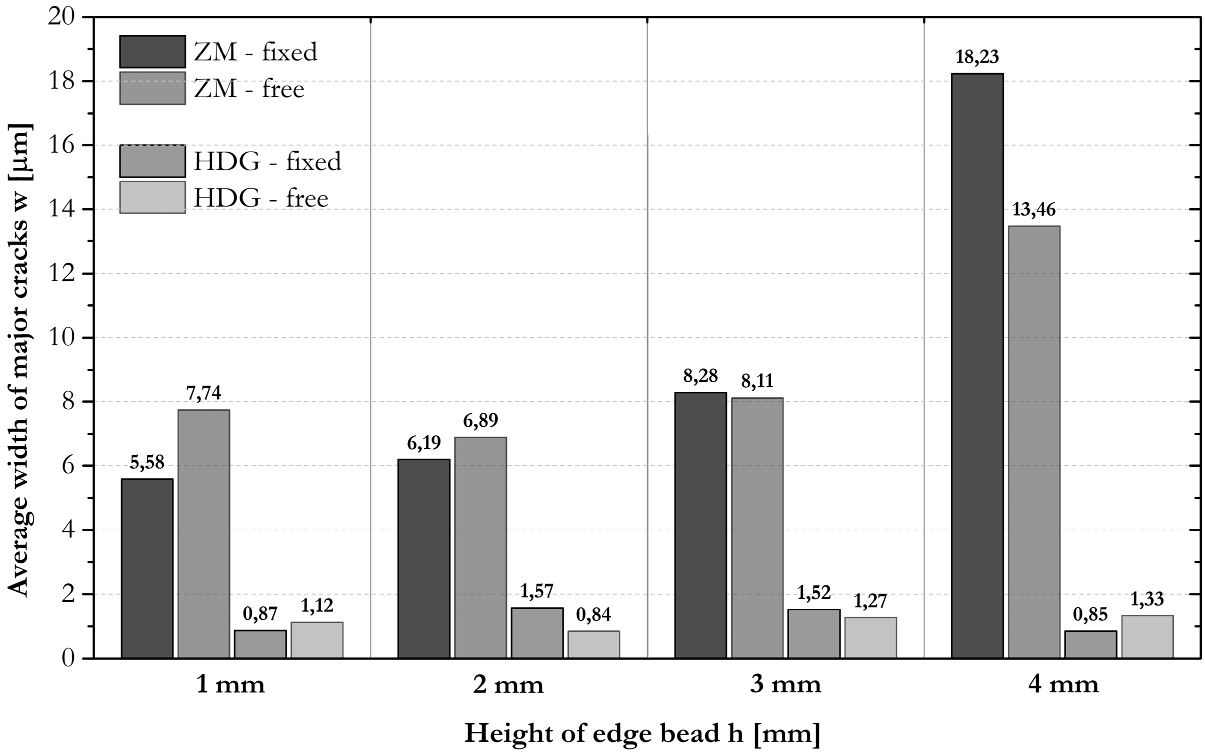


Fig. 5 *Heights of edge beads h [mm] vs average width of major cracks w [µm]*

In Fig. 6 are shown images from the electron microscope of the surface damage for the ZM coating and the height of edge bead 1 mm and 2 mm, respectively. So-called fixed method was used in this case.

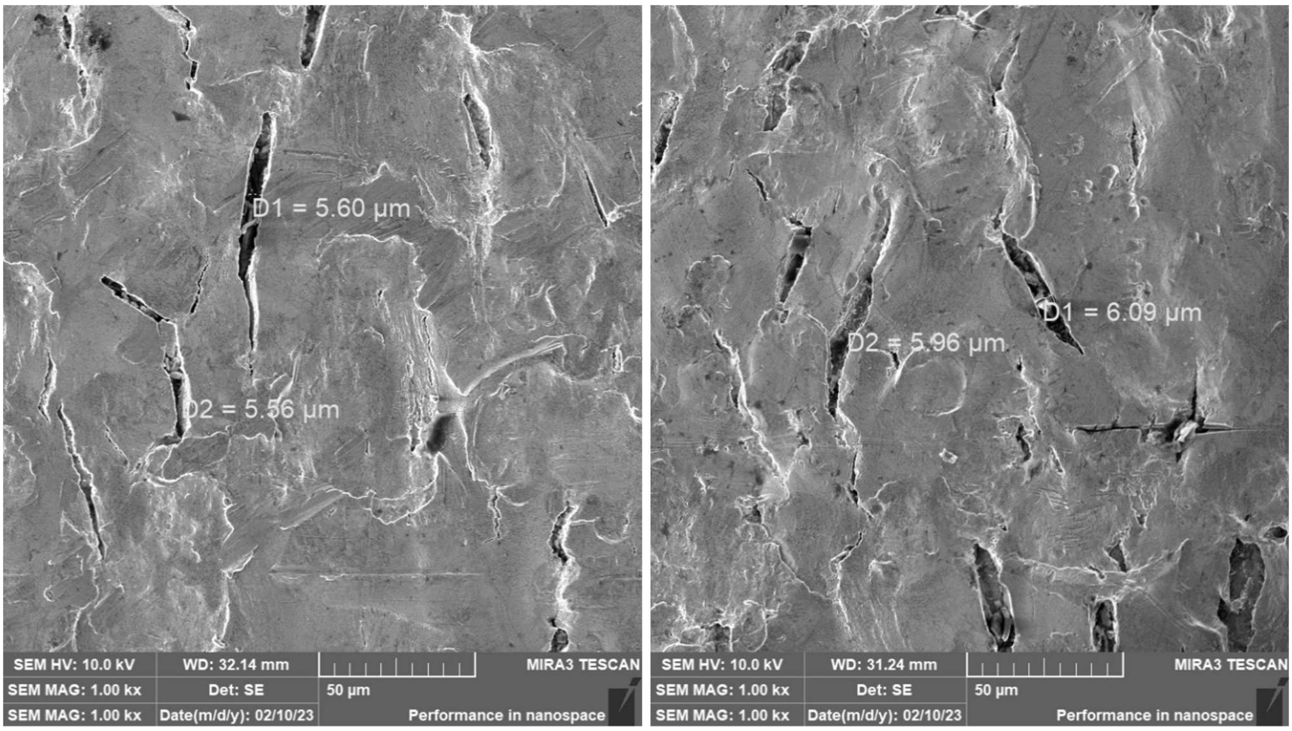


Fig. 6 *Surface damage of the ZM coating - height of edge bead: 1 mm (left) and 2 mm(right); fixed method*

In Fig. 7 are shown images from the electron microscope of the surface damage for the coating ZM and the height of edge bead 3 mm and 4 mm, respectively. Again, so-called fixed method was used in this case.

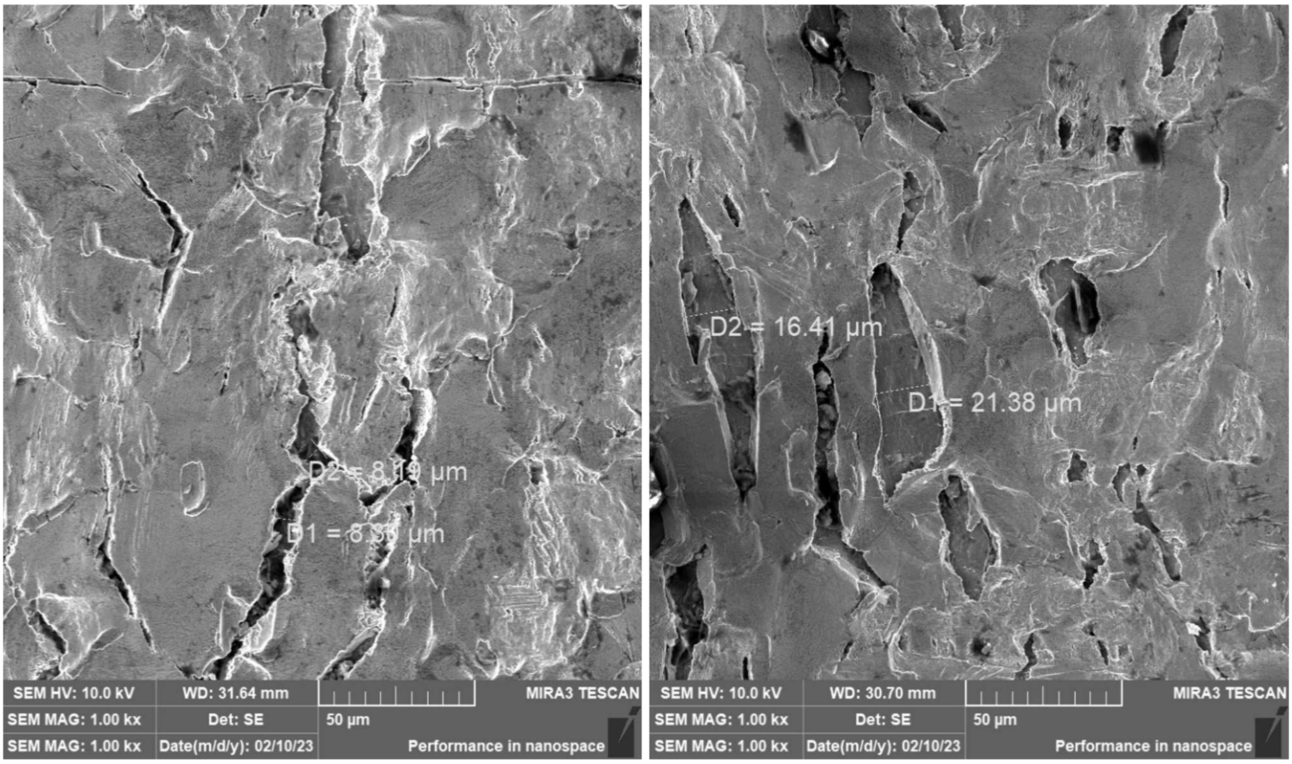


Fig. 7 *Surface damage of the ZM coating - height of edge bead: 3 mm (left) and 4 mm(right); fixed method*

In Fig. 8 are shown images from the electron microscope of the surface damage for the ZM coating and the height of edge bead 1 mm and 2 mm, respectively. So-called free method was used in this case.

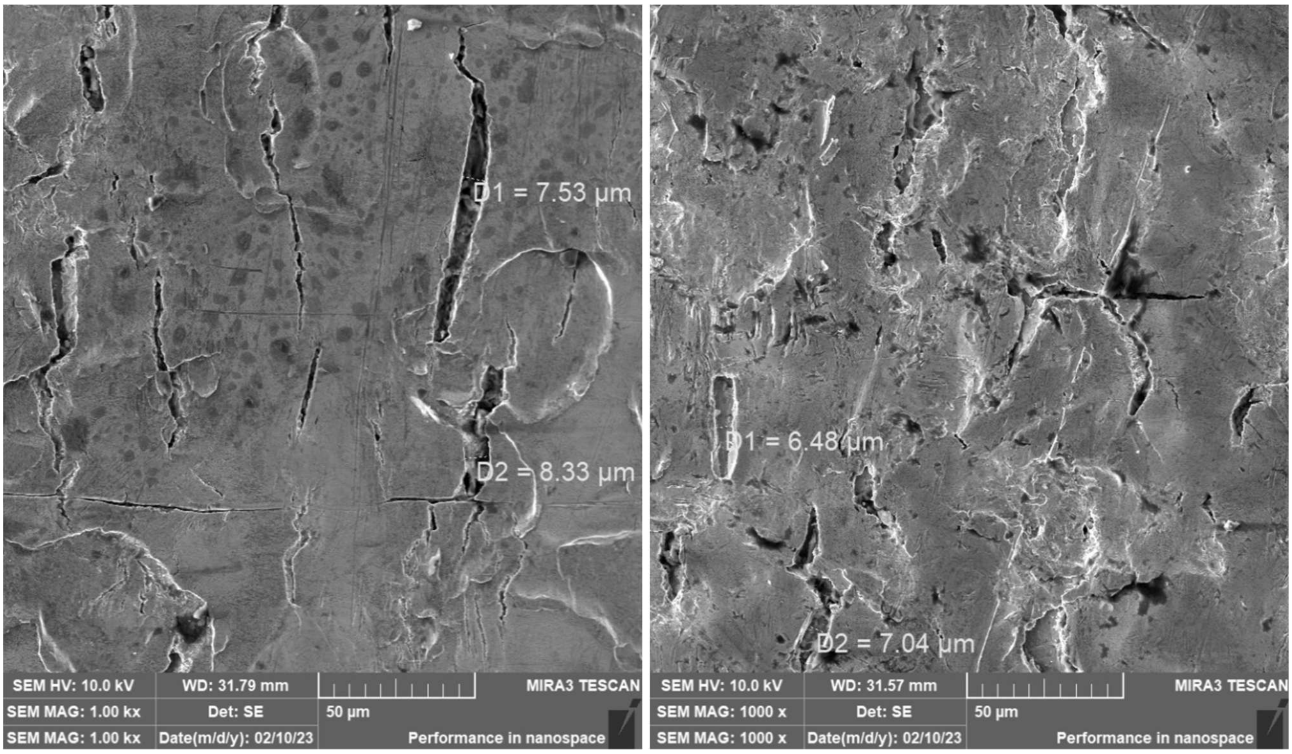


Fig. 8 *Surface damage of the ZM coating - height of edge bead: 1 mm (left) and 2 mm(right); free method*

In Fig. 9 are shown images from the electron microscope of the surface damage for the coating ZM and the height of edge bead 3 mm and 4 mm, respectively. Again, so-called free method was used in this case.

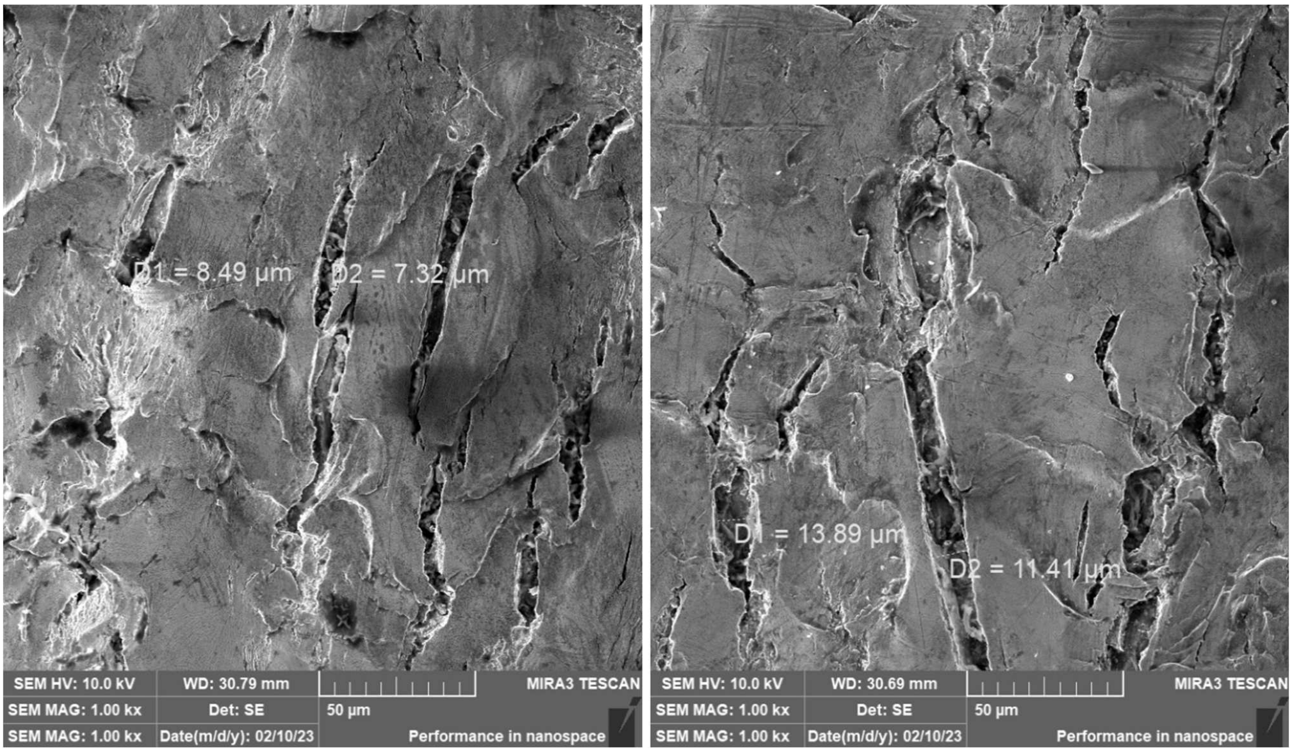


Fig. 9 *Surface damage of the ZM coating - height of edge bead: 3 mm (left) and 4 mm(right); free method*

In Fig. 10 are shown images from the electron microscope of the surface d damage for the HDG coating and the height of edge bead 1 mm and 2 mm, respectively. So-called fixed method was used in this case.

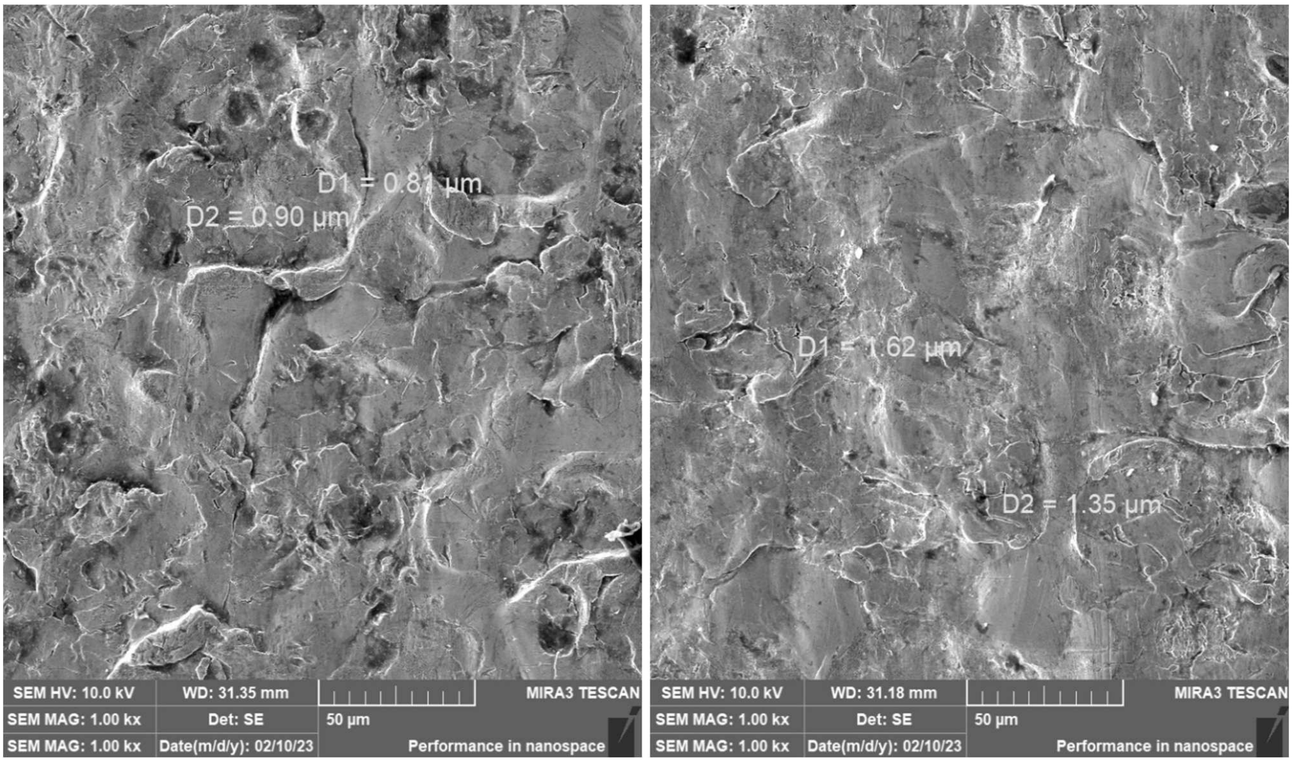


Fig. 10 *Surface damage of the HDG coating - height of edge bead: 1 mm (left) and 2 mm(right); fixed method*

In Fig. 11 are shown images from the electron microscope of the surface damage for the coating HDG and the height of edge bead 3 mm and 4 mm, respectively. Again, so-called fixed method was used in this case.

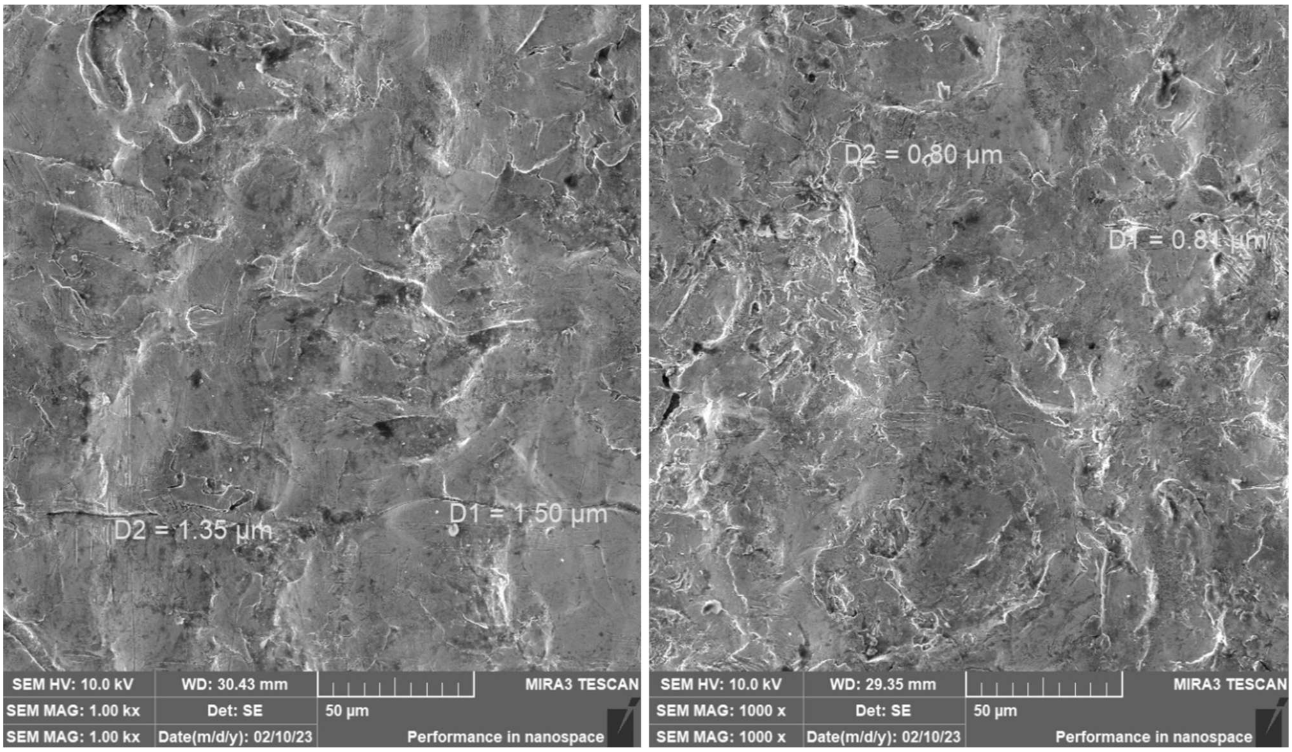


Fig. 11 *Surface damage of the HDG coating - height of edge bead: 3 mm (left) and 4 mm(right); fixed method*

In Fig. 12 are shown images from the electron microscope of the surface damage for the HDG coating and the height of edge bead 1 mm and 2 mm, respectively. So-called free method was used in this case.

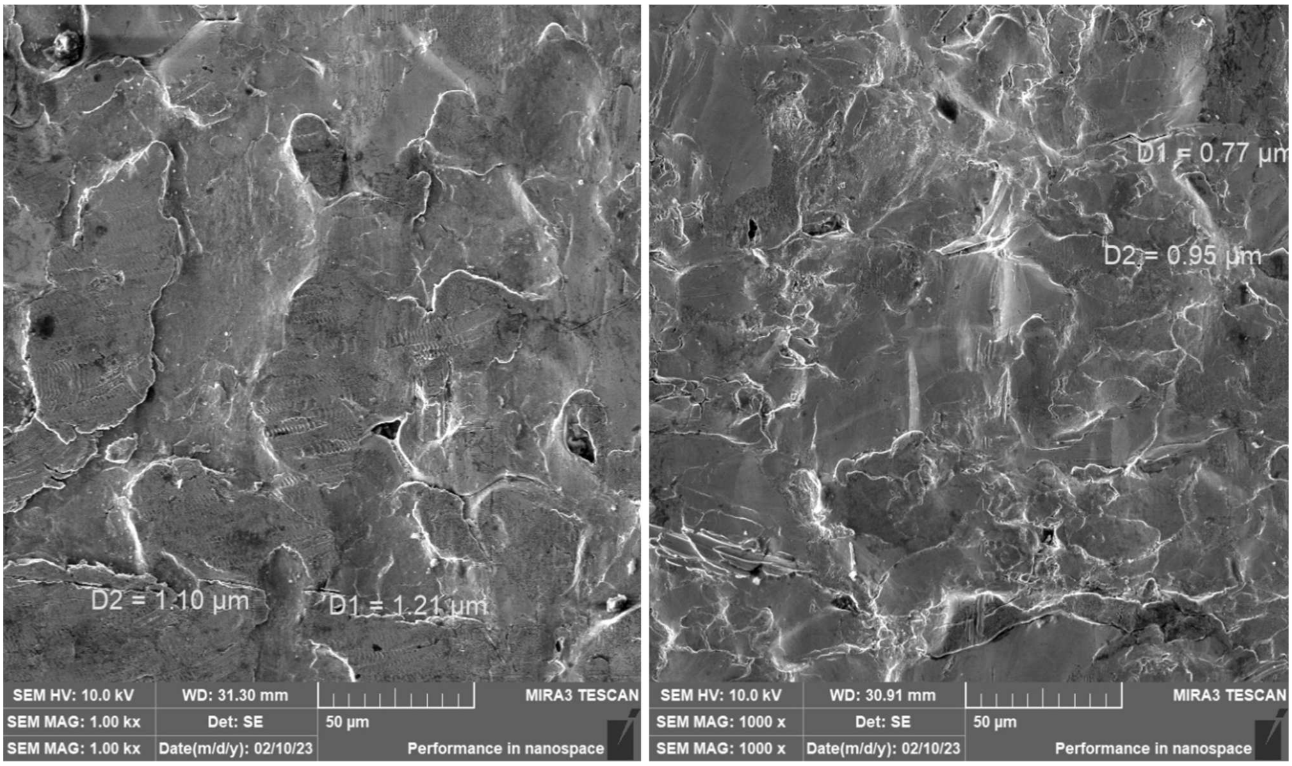


Fig. 12 *Surface damage of the HDG coating - height of edge bead: 1 mm (left) and 2 mm(right); free method*

In Fig. 13 are shown images from the electron microscope of the surface damage for the coating HDG and the height of edge bead 3 mm and 4 mm, respectively. Again, so-called free method was used in this case.

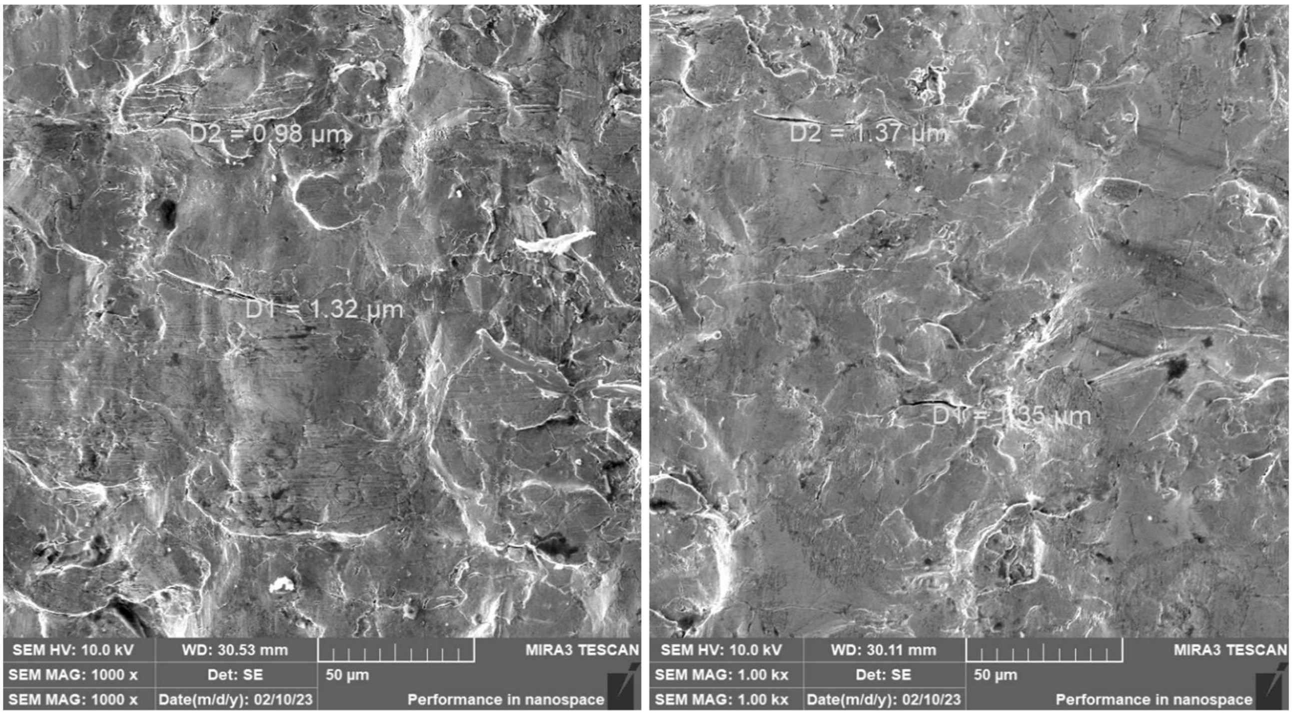


Fig. 13 *Surface damage of the HDG coating - height of edge bead: 3 mm (left) and 4 mm(right); free method*

5 Discussion of results

Based upon the measured results, two major dependences can be concluded. The first one is valid when it comes to the actual comparison of conventional coating (HDG in this case) and the newly developed zing-magnesium coating (ZM). It is obvious that used tribological testing of ZM coating revealed much higher sensitivity of this coating to the cracking already from the lowest used height of edge bead (1 mm). Regarding the measured average width of the major cracks in the case of HDG coating and the relevant height of edge bead as the reference values (100 %), ZM coating revealed many times higher values. Numerically, in the case of fixed method, it was as following: +541,1 % for 1 mm height of edge bead; + 294,3 % for 2 mm; + 449,7 % for 3 mm and finally + 2044,7 %times higher in the case of 4 mm, which is quite huge difference between tested coatings. Considering the free method there was determined: + 591,1 % for 1 mm; + 720,2 % for 2 mm; +538,6 % for 3 mm and finally + 912,0 % for 4 mm. Thus, the similar trends from the used methods point of view.

The second major dependence deals with influence of increasing height of edge beads (1 – 2 – 3 – 4 mm). Generally, there can be stated that the higher height of edge bead, the bigger width of major cracks in the case of ZM coating. Regarding the results of ZM coatings for the height of edge bead 1 mm as the reference ones (100 %), the most important findings just for ZM coating can be summarized as following. In the case of fixed method, there was determined that the higher height of edge bead, the bigger width of major cracks (+ 10,9 %; + 48,4 % and finally + 226,7 %). Such dependent is not so strong in the case of free method, where were measured following differences: - 11,0%; + 4,8 % and + 73,9%. There should be noticed that influence of the tribological testing method was not so strong in the case of HDG coating.

Already from these results it is clear, that ZM coating is very brittle and thus sensitive to cracking, as there was already mentioned in the chapter 2. These results are in good agreement e.g. with the research of Dutta et al. [18], where was approved that the higher content of Mg results in the higher hardness, which also means much higher sensitivity to surface cracking at metal forming. Moreover, Yao et all. [19] made the same conclusion as they observed the distribution of Mg content in Zn-Mg coating in the thickness direction. They found that the amount of Mg is the highest right in the surface layer, which finally also leads to crack formation on the coating surface. Another interesting research also regarding the brittleness of coatings containing zinc and magnesium was done by Ahmadi et al. [20], where was tested that also deformation mechanism related to the microstructure significantly influence the cracking sensitivity of such containing. It is clear from the results that the higher grain refinement decreases the tendency for cracking and enables better surface coating quality.

6 Conclusion

In this article was tested the newly developed zinc-magnesium coating (marked as ZM) from the tribological point of view. So-called edge beads with different heights were used during the experiment. As a monitored quantity, average widths of the major cracks were determined from the scanning electron microscope. To compare the results with the reference ones, the conventional hot dip galvanized (HDG) zinc coated sheet was also tested.

The main objective of the submitted experiment in this article was to test quite newly developed surface coating (ZM – zinc-magnesium coating) under the severe tribological conditions – thus so-called edge beads with different geometry were used. From the images of surface damage, it is obvious that there is quite severe damage of this coating after the tribological testing. Average width of the major cracks on ZM coating is already about 6 μm in the case of the lowest height of edge bead (1 mm). In addition to that, the higher height of edge bead, the bigger width of major cracks in the ZM coating. Influence of the edge beads geometry was much smaller (almost negligible) in the case of HDG coating.

When comparing ZM coating with the common one (HDG), it is noticeable that ZM coating reveals more severe damage of surface – it is mostly 6-times higher considering cracks width. In the case of the highest height of edge bead (4 mm) it was even 20-times higher in the case of fixed method and 10-times higher for free method. Generally, results from this tribological testing are not very favourable for the ZM coating. As a next step, there should be performed mainly tests regarding the corrosion resistance of this coating as well as the influence of different lubricants or deformation rate.

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